TU/e EINDHOVEN UNIVERSITY OF TECHNOLOGY

Collaborative design support : workshops to stimulate interaction and knowledge exchange between practitioners

Citation for published version (APA):
Quanjel, E. M. C. J. (2013). *Collaborative design support : workshops to stimulate interaction and knowledge exchange between practitioners*. [Phd Thesis 1 (Research TU/e / Graduation TU/e), Built Environment]. Technische Universiteit Eindhoven. https://doi.org/10.6100/IR750600

DOI:
10.6100/IR750600

Document status and date:
Published: 01/01/2013

Document Version:
Publisher's PDF, also known as Version of Record (includes final page, issue and volume numbers)

Please check the document version of this publication:

• A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher's website.
• The final author version and the galley proof are versions of the publication after peer review.
• The final published version features the final layout of the paper including the volume, issue and page numbers.

Link to publication

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Download date: 26. Aug. 2022

Collaborative Design Support

Workshops to stimulate interaction and knowledge exchange between practitioners

PROEFONTWERP

ter verkrijging van de graad van doctor aan de
Technische Universiteit Eindhoven, op gezag van de
rector magnificus, prof. dr. ir. C.J. van Duijn, voor een
commissie aangewezen door het College voor
Promoties in het openbaar te verdedigen
op woensdag 23 januari 2013 om 16.00 uur.

door

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geboren te Heerlen

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Financial support for printing this thesis by Eindhoven University of Technology and Avans University of Applied Sciences is gratefully acknowledged.

A catalogue record is available from the Eindhoven University of Technology Library

ISBN:
NUR:

Keywords: collaborative design, workshops, knowledge exchange, Morphological Overview, observation- and interaction-format

Text corrector: Duncan Harkness
Cover design by: Paul Verspaget
Layout: Emile Quanjel
Printed by: Ipskamp Drukkers B.V., Enschede, The Netherlands

Published as issue 177 in the *Bouwstenen* series of the Faculty of Architecture, Building and Planning of the Eindhoven University of Technology.

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SUMMARY – ENGLISH

The title of this thesis is *Collaborative Design Support,* a Technological Design for Workshops that stimulates interaction and knowledge exchange between practitioners.

The focus of this research project is on the effectiveness of Collaborative Design activities of practitioners. More specifically, the research project focuses to interaction and knowledge exchange between two specific practitioners, Architects and Contractors, with a different educational background working together to create Integral Designs for roofs. Integral Designs are designs that can fulfill the requirements from the built environment and comprise realization-knowledge. The contribution of realization-knowledge in the design is necessary because it will prevent failures, realization costs and affects durability of the building and the built environment. The choice for roofs is based on the fact that roofs became an important location for the placement of 'innovative' renewable energy systems and solutions to improve the performance and sustainability of buildings. However, despite the growing importance of the roof to the building design, there is a lack of practical knowledge about roofs by Architects, and Collaborative Design scenes were practitioners, Architects and Contractors, work together and interact to exchange the necessary knowledge. So, a knowledge gap between design and construct exists that prevent the creation of Integral Designs for roofs. The Problem Definition for this research project is therefore formulated as follows: there is a lack in practice of Collaborative Design scenes were practitioners – Architects and Contractors – can interact and exchange object- and realization-knowledge working on design tasks to produce Integral Designs that comprise realization knowledge.

The need for this research project is twofold: First; widely published studies on practice point to a general lack of Collaborative Design teams working on complex building projects. Second, when multidisciplinary Collaborative Design teams have worked on complex building projects, the final design concepts often proved inadequate to deliver an integral designed solution. The result of this unsatisfactory practice is the risk to an increasing amount of failure costs in the Dutch Building & Construction Industry. Recent studies of Collaborative Design teams in the Netherlands show that poor interaction and knowledge exchange are key factors contributing to the failures mentioned above. This is especially true for Collaborative Designs for roofs as shown by literature-studies and the Case Studies presented in this research project. Previous research and literature studies about Design Teams confirmed that workshops are suitable practical scenes for practitioners to be used for observation and analyses in executing semi-experimental research.

The contention of this research project is that a specific scene for Collaborative Design - the Collaborative Design Workshop – leads; first: to interaction and knowledge exchange between the practitioners involved and second: stimulates interaction and knowledge exchange for Integral Designs for roofs by incorporating realization knowledge.

The Design Research Methodology (DRM) is used for this research project to observe, analyze and find possibilities to stimulate interaction and knowledge exchange between Architects and Contractors in a Collaborative Design scene. The DRM is suitable for this research project because of its iterative nature that allows the researchers to improve their research method during the research process and producing a Technological Design as a result. A workshop with a specific setting: a Collaborative Design Workshop was developed and tested in a Practice Setting. Key-components were identified that affect the design activities in such a workshop: the Design Task, the Collaborative Design Team, the Practice Setting and the Design Support Tool. As Design Support Tool, the Morphological Overview (MO) is used because it provides an opportunity to design teams to collect, notate and discuss all aspects of the design task, like function-types and related sub-solutions with different levels of abstraction, in a methodical and structured way. During the DRM research process, which is executed in four stages, analyzing formats were developed for the data of observation of the design

activities and the interaction and knowledge exchange between the two practitioners: Architects and Contractors. The output of the Collaborative Design Workshops was evaluated with the participants using specific evaluation forms and questionnaires developed by the researchers. This evaluation took place directly after the workshop and six months later to observe the affect of the workshop and the use of the MO on Architects and Contractors in practice. Based on the outcomes of analyzes and evaluations the, so called: Definitive Collaborative Design Workshop was defined and finally tested in the last stage of the DRM. In this final stage also the four analyzing and evaluation formats were tested: the Video Observation Format, the Video Interaction Format, the Morphological Analyzing Format and Evaluation Formats.

The results of this research project show that a variety of media was used by both Architects and Contractors throughout the different design-task settings in the Definitive Collaborative Design Workshops. To determine the type of knowledge that is necessary a reference-list was compiled based on the competence-profiles of the practitioners. The outcomes show a wide variety of object- and realization-knowledge that is notated by the practitioners in such a Collaborative Design scene, notated as so called function-types and sub-solutions related to the reference-list. The outcomes show that realization-knowledge was used by notations in the MO of both practitioners: Architect and Contractor in three out of seventeen Collaborative Teams. This indicates that the MO, when being loosely introduced in a design team, is suitable as a supportive tool to stimulate interaction and knowledge exchange however its effect decreases after using the MO for the second time. Regarding collaboration aspects, the outcomes show that in some Design Task Settings the Architects play a more dominant role compared to the Contractors. However, the analyses of the Contractors role in design tasks showed they could communicate a substantial amount of function-types and sub-solutions in all settings. Significant about this is that although the Architect's notations showed a majority, the Contractors could put forward additional notations. These outcomes indicate and provide some evidence that the developed Collaborative Design Workshop can provide for Architects and Contractors, an effective scene to interact and exchange realization-knowledge besides object-knowledge.

The final result of this research project is the Technological Design as presented: the Collaborative Design Workshop and the CD Protocol for its use. This CD Protocol consists of two parts: The first part concerns the organizing and management aspects for executing the Collaborative Design Workshop. The second part concerns the description for the observation and analyzes to execute and the judgment of the outcomes of the analyzes using the formats that are developed. These formats are: the VOF (Video Observation Format), the VIF (Video Interaction Format), the MAF (Morphological Analyzing Format) and Evaluation Formats.

Finally it might be concluded that the outcomes of this research project, using the DRM and a design support, provide evidence that, by the application of the Technological Design guided by the CD Protocol, it is possible to stimulate interaction and knowledge exchange – especially realization-knowledge – between Architects and Contractors to realize Integral Designs in the early design phase.

SUMMARY – DUTCH

De titel van dit Proefontwerp is *Collaborative Design Support,* een ontwerp voor Workshops om interactie en kennisuitwisseling tussen professionals uit de praktijk te stimuleren.

Dit onderzoeksproject heeft de focus op de effectiviteit van Collaborative Design (CD) activiteiten van deze professionals uit de praktijk. Meer specifiek richt dit onderzoeksproject zich op de interactie en kennisuitwisseling tussen twee type professionals. Architecten en Aannemers, met verschillende onderwijsachtergrond die samen werken aan de ontwikkeling van Integrale Ontwerpen voor daken. Integrale Ontwerpen zijn ontwerpen die kunnen voldoen aan alle eisen voor de gebouwde omgeving en tevens uitvoeringskennis bevatten. De bijdrage van uitvoeringskennis in het ontwerp is noodzakelijk omdat dit bouwfouten en uitvoeringskosten zal verkleinen en een positieve bijdrage kan leveren op de duurzaamheid van de gebouwen in de gebouwde omgeving. De keuze voor daken is gebaseerd op het feit dat daken een belangrijke locatie zijn geworden voor toepassing van innovatieve duurzame energiesystemen en voor oplossingen om de duurzaamheids prestaties van die gebouwen te verbeteren. Echter, ondanks deze toenemende betekenis van het dak voor het gebouwontwerp, is er een gebrek aan praktische kennis over daken bij Architecten en een gebrek aan CD situaties. Situaties waar professionals, Architecten en Aannemers, samen kunnen werken door interactie en kennisuitwisseling met elkaar. Kortom, er is een kenniskloof tussen ontwerp en uitvoering die de ontwikkeling van Integrale Ontwerpen voor daken frustreert. De probleem definitie voor dit onderzoeksproject is daarom als volgt geformuleerd: er is een gebrek in de praktijk aan CD situaties waarin professionals – Architecten en Aannemers – kunnen werken aan ontwerpopgaven door het uitwisselen en toepassen van ontwerp- en uitvoeringskennis voor het ontwikkelen van Integrale Ontwerpen die uitvoeringskennis bevatten.

De noodzaak voor dit onderzoeksproject is tweeledig. Ten eerste; zeer breed gepubliceerde studies uit de praktijk laten een algemeen gebrek zien aan CD teams die werken aan complexe bouwprojecten. Ten tweede; als multidisciplinaire CD teams samenwerken aan complexe bouwprojecten, leidt dit vaak tot ontwerpconcepten die ontoereikend zijn als een integrale ontwerpoplossing. Het resultaat van deze onbevredigende praktijksituatie is het risico op toenemende faalkosten in de Nederlands Bouw Industrie. Recente studies naar CD teams in Nederland laten zien dat onvoldoende interactie en kennisuitwisseling sleutelfactoren zijn als oorzaken van de fouten zoals genoemd. Dit geldt speciaal voor Collaborative Designs voor daken zoals de literatuurstudies en Case Studies uit dit onderzoeksproject laten zien. Eerder onderzoek en literatuurstudies over Ontwerp Teams bevestigen dat workshops passende praktijksituaties zijn voor professionals en om te gebruiken voor observatie en analyse in het uitvoeren van semi-experiment onderzoek.

De bewering in dit onderzoeksproject is dat een specifieke CD situatie – de Collaborative Design Workshop (CD Workshop) – zal leiden tot, ten eerste: interactie en kennisuitwisseling tussen de betrokken professionals en ten tweede: interactie en kennisuitwisseling voor het ontwikkelen van Integrale Ontwerpen voor daken die uitvoeringskennis bevatten zal stimuleren.

In dit onderzoeksproject wordt de Design Research Methodology (DRM) gebruikt om mogelijkheden te vinden die interactie en kennisuitwisseling tussen Architecten en Aannemers in CD situaties bevorderen en deze situaties te observeren en te analyseren. De DRM is geschikt voor dit onderzoeksproject omdat de iteratieve eigenschappen ervan de onderzoeker mogelijkheden biedt om de onderzoeksmethode te verbeteren tijdens het onderzoeksproject met een Proefontwerp als resultaat. Hiervoor is een workshop in een specifieke situatie in een Praktijk Situatie ontwikkeld en getest: een CD Workshop. Sleutelbegrippen die de ontwerpactiviteiten beïnvloeden in een dergelijke workshop zijn hiervoor vastgesteld: een Ontwerp Opgave, een CD Team, een Praktijk Situatie en een Ontwerp Hulpmiddel (Design Support Tool), Als Ontwerp Hulpmiddel is het Morfologisch Overzicht (MO) gebruikt omdat het aan het ontwerpteam de mogelijkheid biedt om alle aspecten van het

ontwerp, zoals functietypes en suboplossingen op verschillend abstractieniveau, op een methodische manier gestructureerd te verzamelen, te noteren en te bediscussiëren. Tijdens het DRM onderzoek proces, dat in vier fases is uitgevoerd, zijn analysehandleidingen ontwikkeld voor de data van de waarnemingen van de ontwerpactiviteiten van Architecten en Aannemers. Het nuttig effect van de CD Workshops is geëvalueerd met de betrokken professionals door middel van een ontwikkelde vragenlijst. Deze evaluatie vond direct na de workshop plaats en zes maanden na de workshop door middel van een interview om het effect van de workshop en het gebruik van het MO door Architecten en Aannemers in de praktijk te achterhalen. Gebaseerd op de uitkomsten van de analyses en evaluaties is de zogenaamde Definitive CD Workshop bepaald en getest in de laatste fase van de DRM. In deze laatste fase zijn ook vier analyse en evaluatiehandleidingen ontwikkeld en getest: het Video Observation Format, het Video Interaction Format, het Morphological Analyzing Format en de Evaluation Formats.

De resultaten van dit onderzoeksproject laten zien dat er een variëteit aan verschillende media gebruikt werd door zowel Architecten als Aannemers tijdens de diverse ontwerpopgaven in de Definitieve CD Workshops. Om het noodzakelijk soort kennis te achterhalen dat werd gebruikt en genoteerd werd een zgn. referentielijst samengesteld gebaseerd op de competentieprofielen van de professionals en bijbehorende Professionele Organisaties. De uitkomsten laten zien dat een grote verscheidenheid van ontwerp- en uitvoeringskennis, functietypes van de referentielijst en mogelijke deeloplossingen, genoteerd wordt in dergelijke CD situaties. De uitkomsten laten ook zien dat er uitvoeringskennis werd gebruikt en genoteerd in het MO door beiden professionals, Architecten èn Aannemers, in drie van de zeventien teams. Dit geeft een indicatie dat het MO een passend ontwerphulpmiddel is om interactie en kennisuitwisseling te stimuleren, als het vrij gebruikt kan worden door het ontwerpteam, Het positieve effect neemt echter af als het MO de tweede keer wordt aangeboden als hulpmiddel. In relatie tot andere samenwerkingsaspecten blijkt dat de Architecten in sommige situaties voor de Ontwerp Opgaven een dominantere rol spelen vergeleken met de Aannemers. Hoewel, de analyses laten ook zien dat de Aannemers in alle situaties een substantieel aantal functietypes en deeloplossingen konden inbrengen. Opmerkelijk is ook dat hoewel de Architecten de meeste onderwerpen noteerden, de Aannemers een reeks aanvullende onderwerpen konden noteren. Deze uitkomsten geven een indicatie en een voorzichtig bewijs dat de ontwikkelde CD Workshop aan Architecten en Aannemers een effectieve situatie kan bieden voor de interactie en kennisuitwisseling van ontwerp- en uitvoeringskennis.

Het uiteindelijke resultaat van dit onderzoeksproject is het Proefontwerp; een CD Workshop en een CD Protocol voor het gebruik ervan. Dit CD Protocol bestaat uit twee delen. Het eerste deel bevat aspecten voor de organisatie en uitvoering van de CD Workshop. Het tweede deel bevat een beschrijving en handleiding voor de uitvoering en beoordeling van de observaties en analyses, gebruikmakend van de ontwikkelde handleidingen hiervoor. Deze handleidingen zijn: het Video Observation Format (VOF), het Video Interaction Format (VIF), het Morphological Analyzing Format (MAF) en de Evaluation Formats.

Ten slotte mag aan de hand van de uitkomsten van dit onderzoeksproject geconcludeerd worden dat het in de DRM ontwikkelde Proefontwerp met het CD Protocol als handleiding en gids, het mogelijk maakt om in de conceptfase van het ontwerp de interactie en kennisuitwisseling – met name uitvoeringskennis – tussen Architecten en Aannemers te stimuleren voor het ontwikkelen van Integrale Ontwerpen.

1 INTRODUCTION

This research project is about Collaborative Design Support. The focus is on Collaborative Design scenes in the Building Industry and on interaction and knowledge exchange between practitioners in these scenes. In this Chapter these main aspects; interaction and knowledge exchange between participants in Collaborative Design scenes are explained and discussed. Based on the conclusions of the discussion the focus and Problem Definition for this research project is formulated with its aims and objectives.

Nowadays almost all complex artifacts, including physical artifacts from aerospace, as well as informational such as software, organizations, business processes, plans and schedules, are defined via the interaction of many participants working on different elements of the design, called the Collaborative Design process (Klein et al. 2003). Klein from MIT does research on Collaborative Design processes and develops tools for more effective Collaborative Design for complex physical and software artifacts. Klein (2003) defines Collaborative Design as; the process of designing an artifact (physical as well as behavioral ones), which can be represented as a set of issues each with a unique value, by multiple participants, each potentially capable of proposing and exchanging values for design issues and /or evaluation these choices from their own particular perspective. Kleinsmann (2006, page 30) defines Collaborative Design as “The process in which actors from different practitioners share their knowledge about both the design process and the design content (in order) to be able to integrate and explore their knowledge and to achieve the larger common objective; the new product to be designed”.

Based on the described definitions it becomes clear that interaction and knowledge exchange of knowledge are the most essential aspects for a successful Collaborative Design process.

The new artifact or product to be designed by means of a Collaborative Design process can be defined as Integral Design; a design were all disciplines necessary and important are treated as part of, or contained within, the whole building design approach from the early stages of a project (Zeiler et al. 2009, page 211). With the focus in this research project, this definition is complemented with the following definition of an Integral Design: a design that fulfills the requirements actors and factors in a built environment and which inhabits realization-knowledge. Designs which lack realization knowledge will cause failures, realization costs and can affect durability of the built environment. The Collaborative Design process leads to the total design resulting in an Integral Design. In complex designs or artifacts more Collaborative Design processes have to be developed as component and integral part of the Integral Design. This implies different type of teams working on different tasks and in different and sometimes parallel Collaborative Design scenes for an Integral Design. These aspects will be discussed in the first paragraph below.

In a Collaborative Design process different practitioners interact and exchange knowledge related to a specific design task. Through effective and successful communication between practitioners exchange of knowledge is possible. Communication has social-emotional aspects of background, relevance, relationship and situation; aspects of needs and goals and aspects of nature of communication, media used and feedback. Communication involves some form of interaction between a sender and a receiver of a certain message. Knowledge from different participants is needed to develop, execute and maintain the Collaborative Design process as part of the Integral Design. There are different categories of knowledge and different fields and characteristics of knowledge related to the context and type of practitioner. The development, exchange and management of knowledge is essential to realize a Collaborative Design process as part of an Integral Design.

Aspects of communication will be presented in the second paragraph, knowledge aspects are presented in the third paragraph. The fourth paragraph is used to identify the focus of this research project, followed by the Problem Definition with aims and objectives. This chapter is concluded with the Thesis Outline. First part of this chapter has the focus on Integral Designs and Collaborative Design processes.

1.1 INTEGRAL DESIGN AND COLLABORATIVE DESIGN PROCESSES

In this paragraph first causes and aspects of Integral Designs are discussed. In the second part of this paragraph different items of Collaborative Design processes are discussed. First; the use of Collaborative Design (CD) processes, second; characteristics of CD processes and third; research on CD processes.

The need and necessity of Integral Designs is caused by several global developments on energy and waste in society and the built environment. Since the publication of the report of The Club of Rome in the 1970's on the limits of growth (Meadows et al. 1972-2004) and the Oil-crises in the same decade, awareness of environmental problems has increased. One of the most important aspects of environmental efficiency is the necessity for the responsible use of energy and energy production for comfort within buildings. This is important since fossil fuels are finite, population levels are growing at an alarming rate and Global Warming is an increasing problem (Randall & Randall 2001; Fali & Simpson 2004; Gore 2006; Levin & Tirpak 2009).

The main impact of global aspects related to the Building Industry and associated issues include the increasing refuse production and waste of materials and energy sources. Of all produced materials 50% are used in the Building Industry and this industry is responsible for 50% of the total waste production. Significantly, the Building Industry uses 40% of the total energy production (Wackernagel & Rees 1997; Ohl & Wolf & Anderson 2008). With these issues in mind, a more efficient and sustainable Building Industry is therefore necessary. The growing consciousness about these global aspects and a more sustainable Building Industry has occurred against the backdrop of a growing complexity in building design for the Building Industry (Baccarini 1996; Dubois & Gadde 2001; Fernández-Solís 2007).

The impact of this complexity towards the Building Industry can be viewed by recent studies on failure costs in the Dutch Building Industry. Studies by USP Marketing Consultancy show a substantial increase of failure costs each year; 7,7% of the total turnover in 2001, 10,3 % of the total turnover in 2004 up to approximately 11,3% for 2008 (2008, 2010). Based on the figures of the EIB (Economisch Instituut Bouwnijverheid) the total building production is € 55 billion and, if translated to money, failure cost incorporates a 'waste' of € 6.2 billion over the last year.

The main causes of failures as described in the studies of USP and EIB-research points to poor project preparation leading to costly remodeling and changes during the construction phase. Other main influences are a lack of partnerships, which causes coordination faults; a lack of project evaluation, and a lack of adherence to the agreements made. The main point stated is that within the Dutch Building Industry there is still too much focus on working and financial performance on the project-level instead of working on improvement of the processes of preparation, construction and maintenance. Improvements on the process level should be part of the necessary culture change needed to improve practitioner's competences for the design and realization of buildings (Quanjel & Zeiler 2003, 2009, Zeiler & Quanjel 2007; Zaal 2004; Goossens 2006; USP 2008, 2010).

The seriousness of these issues is now well understood and accepted throughout the majority of the Building Industry. Within the Dutch Building Industry, for example, there is a growing realization of the serious need to improve its efficiency. Simultaneously, however, there is also a growing acceptance that traditional approaches to organize and plan these (construction) processes will no longer suffice (van Aken 2005). Traditional approaches will actually lead to the reuse of existing solutions by way of optimization or redesign. As such, there have been many calls for better organization of the design process (Friedl 2000; Wichers Hoeth and Fleuren 2001) and the design process related to the building process (van der Helm et al 2002; Boudewijn en Broekhuizen 2009).

Practitioners who are part of Collaborative Design Teams for Integral Designs need to have a view to engender the necessary culture change to facilitate the timely input of a broader range of professional practitioners to develop and execute Integral Designs and different aspects which influence this development such as collaboration formats, contract formats, stakeholders interests, clients and professionals; attitude, knowledge and skills (Cohen et al. 2002; Quanjel & Zeiler 2003, 2009; Zaal 2004; Geerlings 2005; Ang 2007). Many of these approaches consider it necessary to challenge the traditionally dominant role of the Architect by giving more importance to collaboration with other largely engineering based practitioners in the early stages of the design process to realize an Integral Design (Habraken 2005; Cook 2007). Goossens explains in more detail how teams for this purpose in Integral Design processes should be organized and which competences are needed (2006). Where Goosens uses Integral Design processes in his research, Collaborative Design processes are used in the current research project for scenes were practitioners with different educational background work collaboratively on a specific design task. Other definitions such as Integrated Design have the same core characteristics as Integral Design and Collaborative Design: these are processes were it is necessary that practitioners with different background interact and exchange knowledge to fulfill complex design tasks.

Achieving the necessary culture change on collaboration through synergy of practitioners requires simultaneous development of respect, knowledge and skills through knowledge management of practice, research and education on the different levels of the Building Industry; culture, process- and project-level are argued to be crucial (Bax & Trum 2000; Friedl 2001; Quanjel & Zeiler;2003, 2009).

1.1.1 CHARACTERISTICS OF COLLABORATIVE DESIGN PROCESSES IN THE BUILDING INDUSTRY

Collaborative Design in this research project is defined as; the process in which actors from different practitioners share their knowledge about both the design process and the design content [in order] to be able to integrate and explore their knowledge and to achieve the larger common objective; the new product to be designed" (Kleinsmann 2006, p.30). Actors from different practitioners which exchange their knowledge can be defined as teams. To exchange knowledge in the design process and on the design two basic aspects can be identified; exchange of knowledge and communication needed to exchange this knowledge.

Before discussing Collaborative Design related to the defined aspects above, two general aspects are necessary to view. First; general characteristics of design- and construction projects. Second; factors that influence these construction process.

First it is necessary to identify the essential characteristics of design and construction projects of which the Collaborative Design process is part of (Emmitt and Gorse 2003):
- The client and the site; communication culture, type of procurement, regulations, context.
- The individual organizations for design and construct; change in time, contractual arrangements, stakeholders' interest, formal and informal, inter-organizational and organizational.

- The individuals within the various organizations; personal characters / competences, formal and informal, inter-organizational and organizational.
The current research project will focus on the individuals within the various organizations; the other two identified characteristics are variables are not the scope of the research project.

Additionally Chan (Chan et al. 2004) gives the following factors of influence for construction projects. First, human related factors (e.g. experience, client characteristics, project team), Second; project factors (type, complexity, size), Third; project procedures (procurement, tendering), Fourth; project management actions (e.g. communication system, planning, control mechanism) and Fifth; external environment (social, economical, political etc.).

As this overview shows there are many variables related to design and construction projects. These variables and characteristics and the dependence on context and time make that research on comparable situations and aspects for Collaborative Design processes in practice is complicated and difficult to organize and manage. The current research project will focus on the practitioners, within the various organizations and aspects which are related to human related factors of experience with a specific project type and complexity and specific management actions (interaction and knowledge exchange). The other two identified characteristics are variables which beyond the scope of the research project. For the focus of the research project the focus variables will be discussed in the following paragraphs. These variables are related to specific factors for Collaborative Design processes.

In the following paragraphs two aspects are discussed which are related to as well interaction as knowledge exchange: Collaborative Design Teams and Scenes for Collaborative Design Teams.

COLLABORATIVE DESIGN PROCESSES

The product design process shifted in most product-based industries from an individual and rather unorganized activity to a systematic activity performed in a multidisciplinary team (Valkenburg 2000; Hoegl et al., 2004). Buijs and Valkenburg (2005) called this way of organizing product development integrated product design. Well-performed integrated product design processes may result in higher speed to the market, higher quality products that fit the market needs and the possibility of developing products with different functionalities. Collaborative Design processes are applied in many different industries such as automotive industry, aviation industry and industrial design, for physical and informational artifacts (Griffin 1993; MC Donough III 1993; Cooper and Kleinschmidt 1994; Klein 2003; Langerak et al. 2005).

Before different aspects of Collaborative Design processes are discussed it is necessary to point out the main reasons for a Collaborative Design process:
- The big influence of decisions in the beginning of the design process on the cost/quality ratio
- The potential contribution through knowledge and experience of all stakeholders at this beginning
- The growing complexity of building projects e.g. new materials, components and systems related to sustainable energy use, complex locations, complex user-requirements, complex geometries, new building systems and building methods
- The wish of different stakeholders to have an influence on the design because clients demand guaranties and have claims because of building failures
- The waste of time and money in the actual design process where the advice of experts often comes too late because other developments changed the design already.
These reasons result in a necessity to work on specific aspects of the total design task with specific practitioners with different roles and knowledge simultaneously. This organizational way of working collaboratively is used in different other Industries which can be compared with the Building Industry to gain more insight into the characteristics of Collaborative Design.

In contrast to other industries, the design problems faced by the Building Industry are understood to be wicked problems, which require much more thought and present a greater challenge in terms of organising effective collaboration. This greater complexity arises from the fact that a building is not a simple product, but an artifact which contains different products on different levels of abstraction, each of which requires a particular type of collaboration. This point is well captured in the following quote of Kvan, who argues: “Design Collaboration requires a higher sense of working together in order to achieve a holistic creative result. It is a far more demanding activity, more difficult to establish and sustain, than simply completing a project as a team. I suspect that we collaborate far less often than we pretend to.” (2000, page 410).

Types of Collaborative Design scenes during the design of buildings are not common. There is some sparse literature about collaboration on interpersonal level from Modern Architects like Chareau for La Maison de Verre (Vellay et al. 1988, p 17) and le Corbusier for the Dom-Ino and Citrohan houses (Frampton 1980, p 186-189) in the first part of the 20th century. Around the 40’s Wachsmann and Gropius introduced and used a teamwork method (Gropius & Harness 1966). Caudill (1971) promoted teamwork in his book, but if this lead to application in design-processes could not be verified. Brown and Berridge (2001) found partial cooperation for projects such as for example Centre Pompidou by Piano and Rogers in Paris (1972-1977), but mostly not in the early design phase. From studies of Van Loon (1998) and van Gunsteren (2001) some other examples are found, but more related to the preparation of the design than the design itself. With the development of more complex structures in the building industry, Collaborative Design processes during the early phases of the design became more developed in projects of e.g. Gehry, Oosterhuis, Zwarts and Jansma, Asymptote Architects, Erik van Egeraat and Moshe Safdie (Penn 2004; Eekhout 2009).

Due to the reasons described above, Collaborative Design processes have not been used in the Building Industry to the same extent as it has been used in other more commercially focused and industrialized sectors. The use of collaborative approaches in the various industries is reflected in the educational programs offered to the industries. The education of collaborative approaches is an evident part of the curriculum of Industrial Design, but it is still uncommon to see such approaches playing an integral part in the education of Architects and Engineers. Although there is an evolution for example in the Dutch education (Eekhout 2009), this finding still holds true today (McPeek & Morthland 2010). What can be indicated is that education and training of practitioners is an important aspect to work on the lack of applied Collaborative Design processes.

COLLABORATIVE DESIGN TEAMS

Within Collaborative Design Teams and levels of working different types of participants can operate. First; in the setting of participatory Collaborative Design; clients, users (non-practitioners) and practitioners. Second; practitioners with equal educational background. Third; practitioners with different educational background. The current research project is focusing on the Third Collaborative Design-scene; practitioners with different educational background working on a design task. Though, for this research project multidisciplinary teams are defined as teams Collaborative Design Teams were practitioners with different educational background are working on a design task. The current research project is interested and focused in the professional aspects; teams were different practitioners with different educational background (multi-disciplinary) are working together on a design task.

When assembling a Collaborative Design Team, the nature of team dynamics will affect the design and building performance criteria. Success Factors in assembling a Collaborative Design Team careful consideration should be given to: the level of professional experience, the design experience

and the personalities of the team members and to whether the team is sufficiently multi-disciplined (Shen and Liu 2003).

To encourage Collaborative Design Teams to work together, training and education of practitioners is necessary (McPeek & Morthland 2010). The studies of Bierhals et al. (2007) show the following Success Factors on training and education of members of multidisciplinary design teams that the following aspects are important: task related aspects, ways to organize and review group activities and perception of different perspective of thinking due to the background of their disciplines. The later aspect could serve as reference system when specialized knowledge is needed.

SCENES FOR COLLABORATIVE DESIGN TEAMS

To develop Integral Designs by Collaborative Design Teams specific scenes need to be organized were activities for the organizations and the production of design information for a project can take place. Design meetings are commonly used for this purpose; they are part of a routine way of working for organizations within a project as they feature significantly in the organization of the design process. Design team meetings are organized to discuss the design between designers with different knowledge and expertise (Cross and Clayburn Cross 1995). These design team meetings are scenes were practitioners meet in person, to talk and interact in face-to-face situations (den Otter and Emmitt 2007; Emmitt and Gorse 2007; Gorse and Emmitt 2007; Emmitt 2010). Beside of the formal design meetings, improvised or informal design meetings can be distinguished. Improvised design meetings means that they are unplanned, creatively making use of the people beside or after a meeting as a practice which is observed in other situations (Tribelsky and Sacks 2011). These types of design meetings are not part of the scope of this research project because these types of design meetings are not structurally developed and organized in the Building Industry.

When discussing Collaborative Design Teams, the difference with the described types of practitioners normally organized in design meetings, lies in the aspect of practitioners with different educational background. These Collaborative Design Teams consist though of practitioners with design-experience and competences and practitioners with no or preliminary experience and competences with design but complementary experience and competences related to engineering and construction of the design. As shown in the previous paragraphs Collaborative Design scenes in design-meetings are sparse in the Building Industry.

Related to the current research project two aspects are important related to an appropriate scene for Collaborative Design Teams. The first aspect which is needed to be taken into account is that the Collaborative Design scene, although there is a lack of such scenes in practice, needs to be organized in order to train, educate and support these type of Collaborative Design scene and the practitioners involved. Second aspect which is important is that in order to observe whether this training of involved practitioners in the Collaborative Design scene is effective, this implies specific characteristics of this Collaborative Design scene.

Beside of dialogues, informal and formal design team meetings, there is a fourth scene which is used as well in practice as for research: the facilitated workshop. As Emmitt (2010) points out, there are several advantaged related to the aims and use of a workshop. First, they provide a scene for creative interaction, Second; workshops have a central position in Collaborative Design approaches and Third, workshops are valuable for the development of integrated temporary project organizations which is one of the main characteristics of teams within a design- and building process. As main difference with meetings, Emmitt (2010, page 72) distinguishes that workshops are concerned with establishing and developing interpersonal relationships and used in a temporary organizational setting with a listing were workshops can be used for. Important for this research project with the focus on interaction and

knowledge exchange, for the development of the workshop the requirements should be: to create knowledge and explore different perspectives by the practitioners involved.

Additionally to the use of workshops, Emmitt et al. (2004) distinguish five types of workshop as 'creative workshop methods:
- (partnering) Building effective relationships: teambuilding, common goals, ethics in co-operation, roles and partnering agreement
- Vision: basic product values, knowledge and experience, whole life approach
- Realism: fulfilling project values, design alternatives, project economy
- Criticism: presentation of conceptual design, value reflection
- Design planning: production information, delivery, value engineering
- Planning for execution: process plan to map the various production activities

With the focus of the current research project which is related to a problem in practice the type of workshop which has to be developed is the type related to 'realism' which is related to fulfilling project values, design alternatives and project economy.

There are references for experience with workshops as a design team scene used for different purposes. These can be grouped as follows. Workshops for value management (Cristoffersen and Emmitt 2009). Workshops to engender a sense of occasion and collective project-team achievement and/or to encourage inter-project organizational learning and exchange of design ideas (Luck 2011). Workshops are also used in combinations of organizational learning and research (Badke Schaub 1999, van Gassel 2004; Quanjel and Zeiler 2003, 2009; Badke-Schaub 2007; Savanović 2009). Creativity and learning is spatially situated but seldom can the location of situated learning and transfer of knowledge between projects be defined, spatially. A design workshop could convene a time and location for this (Luck 2011, page 12). The workshop therefore should be an appropriate Collaborative Design scene to use for Collaborative Design Teams.

For specific aspects and characteristics of workshops Emmitt (2010, pages 72-75) gives a valuable overview. First; workshops need to be structured to achieve specific aim(s). Second; the amount of individuals related to facilitator(s) and context need to be balanced. Third; to have an effective setting a proper introduction and 'icebreaking' is necessary. This complementary to creating an environment for participants were they can be relaxed and happy to communicate openly and contribute to discussions constructively. The facilitator should create a thrusting atmosphere. Fourth; the influence of the use of interactive media (content and educational), games for socio-emotional development. Emmitt (2010, page 75) also indicates risks and challenges related to the workshop are, First; to avoid overuse of workshops as a scene for practitioners. Second; to avoid the use of similar approaches each time and third; to manage the attendance of the practitioners involved in the workshop. When planning a workshop the following should be considered as characteristics:
- Bringing practitioners together
- As an integral and essential part of the project / training plan
- Make sure that appropriate people will attend
- Make event relevant to the project
- Ensure that decisions are made / communicated / acted upon

Related to the current research project and the use of workshops, the use of workshops have two functions:
- Learning by doing on level of compatibility (competence and expertise) and values; for an individual understanding of fellow contributor's values and preferences for communicating (action learning).
- Observation of Collaborative Design scenes in a relaxed and comparable setting which can be used as semi-experiment for a practical setting (research and practice).

The following aspects are related to successful Action Learning. First, effective learning will take place when practitioners are faced with a real live problem to solve (Argyris and Schön 1978; Schön 1983; Senge1990; Revans 1998). Second; Action Learning is used for members learn to from each other, for applying knowledge and best practice to change their work and for the development of individuals and organizations, bringing about changes in work practices and an increased capacity to learn (Emmitt 2010, p. 156). In Action Learning the following aspect are important for success:
- All group members are viewed as equals with a common aim
- There is no leader or expert member of the group
- There should be a real work challenge
- There should be a facilitator for guiding

One remark has to be made related to the facilitator. When a facilitator is used in a situation, as in the current research project, for as well guiding the workshop as well as a researcher and/or observer this could influence the Collaborative Design Team as well as the research. A strict managing of the roles of the facilitator and tasks related to the managing of the workshop and the research therefore is necessary.

Observation on Collaborative Design is related to research and practice and will be discussed in the next paragraph. What can be concluded about the Collaborative Design Scene is that the workshop is an appropriate scene when is should be used for both support the Collaborative Design Team as well as to observe and study this scene.

RESEARCH ON COLLABORATIVE DESIGN PROCESSES

Research on Collaborative Design processes in brief is related to participatory Collaborative Design and Collaborative Design with practitioners. Participatory Collaborative Design (Sanoff 1973; Spinuzzi 2005) research focuses on collaboration between practitioners and non-practitioners (clients, users) with specific topics but beyond the scope of the current research project which has the focus on collaboration, interaction and knowledge exchange, between practitioners with different educational background.
Main research on Collaborative Design processes with practitioners in industry in general started in the 90's. Most important reviews on the different research topics related to Collaborative Design processes come from Achten (2009), Huang et al. (2010) and Büyüköközkan and Arsenyan (2012). These reviews can be grouped around the following research topics.

A review of Collaborative Design by Achten explains that two distinct research foci on Collaborative Design can be identified in the literature: research into Pedagogical Models and research into Virtual Design Studios (Achten 2002). Important for this analysis was the European Accolade-project (Stellingwerff and Verbeke 2002) which focussed on Collaborative Design in Architecture and featured 29 participants from fourteen European universities and businesses. Achten (2002) points out that there is a tendency on technology driven aspects on scenes and tools.

As part of their extensive study on reference Architecture for Collaborative Design (Huang et al. 2010) identified related to this research project the following topics: First; methods and models developed for Collaborative Design; mainly web-based and managing methods. Second; Collaborative environments developed to facilitate or support Collaborative Design and Third; Applications or case examples of Collaborative Design. All referred research is mainly ICT or web-based and related to managing aspects and tools related to product development , but no references to research on task-based face-to-face research on interaction and knowledge exchange.

Specific on Collaborative Design in product development for Industrial Engineering (CPD), Büyüköközkan and Arsenyan (2012) distinguish three major trends of research. First, CPD—dynamics which attempt to explain CPD-dynamics and use mostly case studies as well as hypothesis testing.

Second, partnership formation in CPD and Third, technologies and methodologies to support Collaborative Design. There extended overview gives the same tendency as the more comprehensive overview of Achten (2005) and Huang et al. (2010).

More specific conclusions from these overviews related to missing items are the following. First; most studies generally focus on one problem in the Collaborative Design process. Second; most proposed technologies and methodologies to support Collaborative Design processes are not checked in reality or lack a plan to plan and implement them according to the requirements. Third; most research is focusing on the Collaborative Design process and not related to the main concern, an effective design. Fourth; organizational learning by increasing corporate experience and knowledge during Collaborative Design process is a rather neglected topic. Fifth: nearly all research is related to Collaborative Design processes concerning practitioners with the same educational background or with non practitioners (clients and users). These lacking items from this overview are part of the current research project to some extent. Regarding the first missing item, this research project has the focus on interaction and knowledge exchange, related to research-domains of communication and knowledge; which is a two-sided problem. This research project wants to address a problem from practice and check the developed 'solution to this problem in a setting which is as realistic as possible; a semi-experiment. Explicitly this research project has the focus on task-based interaction and exchange of knowledge, which is related to the third missing item. This should be accomplished by stimulating and training of practitioners, linked with the fourth item. Most important aspect to the problem in practice, a lack of realization-knowledge used in Collaborative Design processes, is that the current research project focuses on interaction and knowledge exchange between practitioners with different educational background related to design and construct.

Although recent research has been conducted to the characteristics and influences on the Collaborative Design process several authors confirm a lack of clarity of design support in the Building Industry (Kvan 1997; 2000; Achten 2002) and more specifically within the Dutch Building Industry (Oostra 2001; Kleinsmann 2006). Research done on Collaborative Design is mainly focussed on collaboration between designers (Sebastian 2007) or between practitioners with equal educational background (Savanović 2009). However, the research of Sebastian (2007) does not fit in the definition of collaboration in a Collaborative Design process. In his research designers, Architects, are not working collaboratively on one design task but are managed by another practitioner on an urban scale, where the individual designs have to fit in. In this scene the manager is the practitioner who is organizing the collaboration of other practitioners. This contrary to the research of Savanović (2009), where only the scene is organized and the practitioners have to collaborate, interact and exchange knowledge,

Most important research on collaboration in Collaborative Design scenes and especially in Construction is done in the UK by Gorse (2002), Emmitt and Gorse (2003, 2007), Emmitt (2010) and Bouchlaghem (2012). Their research gives an extended overview and insight into the variables and aspects to be considered and how to manage these variables and aspects. Although their focus is on communication and managing aspects during the construction phase and with less focus on the pre-contract phase, the design-phase, where Collaborative Design processes can also play an important role. However, much important results from these studies can be used when studying Collaborative Design processes. All over, the same tendency as for global Collaborative Design research can be concluded for Collaborative Design research in the Building Industry; a strong tendency on technology driven aspects and social-emotional aspects related to design support and a lack of research for an effective design and organizational learning related to design support.

Clarity of design support should provide the right conditions for the practitioners involved, the setting for cooperation and the availability and exchange of knowledge to link design and realization. Because many different aspects influence the success of a Collaborative Design process as can be concluded from research (Gorse 2002; Emmitt and Gorse 2003, 2007; Emmitt 2010; Bouchlaghem 2012), it is

important to pose restrictions on the research focus. A restricted focus is needed to organize a setting to observe the *interaction* and *exchange of knowledge* that links design and realization, and to exclude other aspects. In the following paragraphs these aspects will be discussed and focused to the Problem Definition.

1.2 COMMUNICATION AND COLLABORATIVE DESIGN PROCESSES

As shown, Collaborative Design Teams can be defined as temporary, multidisciplinary and network-based organizations. Working in Collaborative Design Teams on complex design tasks collaboratively needs effective communication between the practitioners involved in design meetings or workshops. Communication can be defined as a system of interaction between sender and receiver (Schramm 1957). Related to the current research project, communication is related to the context of the Building Industry. Much insight is gained from extended studies on communication in the Building Industry by Dainty (2006) and Emmitt and Gorse (2003, 2007).

What follows in this chapter is, First; the discussion about a communication model that can be used in this research project. Second part discusses main aspects concerning communication: levels of communication, types- and richness of communication, scenes of communication. Third part gives a brief overview of research on communication and interaction with the focus on observation and analyzing interaction.

MODELS OF COMMUNICATION

A basic model for communication is the model of Shanon and Weaver (1949) concerning communication as relationships between input and output but does not address what communication achieves and ignores feedback. Schramm (1957) developed this model with regard to the feedback-loop (1963, 1973). Important addition to these basic models was made on a theoretical level by Dretske (1999) who underlined the aspect of meaning of the communicated information which becomes knowledge in a specific context.

Emmitt and Gorse (2003) give an overview of characteristics of communication models which relate to the model of Feldberg (1975) and relevance theory (Spencer & Wilson 1986). The main difference between these two models is that the relevance theory model addresses communication from a human and social-emotional viewpoint. Dainty (2006) introduces several additional models of communication. The first one to address the effects of feedback, in the communication model of Baguley (1994), and the second one to address the effects of cultural context; the communication model of Thompson and Mc Hugh (2002) based on Fisher (1993), partly referring to the theoretical level of Dretske (1999). The feedback aspects of the model of Baquley are comparable to the model of Feldberg; however Feldberg articulates influences on sender's and receiver's messages and relates the feedback with the result(s) of the communication. In the current research project these results of the feedback of messages are essential and to be viewed in the cultural context of the Building Industry

Related to the specific context of Collaborative Design scene the communication model should address more specific aspects and therefore have specific characteristics. Characteristics for the Collaborative Design scene in this research project for interpersonal communication which should be addressed are:

- Needs and goals; task based collaboration through interaction and knowledge exchange
- Background and ability of participants to process information, skills, knowledge, attitude and culture; competence (Shen and Liu 2003).
profiles
- Relevance; task based
- Relationship and situation; Architect and Contractor randomly in Collaborative Design scene; comparable meeting room
- Nature of communication; task based
- Media used; talk, sketch/notations, tools
- Feedback; with media used

Emmitt and Gorse (2003) introduce related to construction communication the communication models of Feldberg and Relevance Theory human aspects such as external pressures, psychological and physical noise, information load, emotional load, motives, thoughts, believes as well as not-verbal aspects are taken into account. What is obvious about these communication models is that they are focused on the socio-emotional aspects and the transformation and contextualizing (cognition) of communicated items. In the current research project these socio-emotional aspects are not part of the research and the focus is on task based aspects and the cognition of these task based items. This focus is addressed, because of the following reasons. First the focus is on interaction and knowledge exchange which is task-based related focusing on communication through speech, notations / sketches and a Design Support Tool. Second is argued that although there are always socio-emotional factors that affect the interaction and knowledge-exchange the group-members will always differ in practice and therefore also the amount of variables related to socio-emotional effects which could not be compared in the current research project. Third; because in the current research project we only can use a relative small sample of practitioners which are also not 'matched' a comparison on socio-emotional factors is not reliable.

All practitioners involved in a project and a Collaborative Design scene need to collaborate, exchange and integrate information and knowledge to realize task based project objectives (Pietroforte 1992; Oxman 1995). For addressing the necessary issues to solve the problem, resolute conflicts and build relationships, face-to-face communication is crucial (Abadi 2005). Face-to-face communication is also the scene which is the most intimate and in potential the achieving the most effective communication. Research In a face-to-face setting the feedback is at a maximum (Trenholm & Jensen 1995) with a maximum of non-verbal messages (Richard and Kroeger 1989). Especially in interpersonal communication this has the risk of polarization and sometimes to communication breakdown (Emmitt and Gorse 2003). Emmitt and Gorse (2003) distinguish three types of interaction related to face-to-face settings; linear, interactional and transactional. With the focus on socio-emotional aspects they argue that the transactional theory offers the only comprehensive attempt to build a complete picture of the communication process. In the current research project however the focus is not on a complete communication process but on task based interaction and knowledge exchange as such and the results from the feedback between sender and receiver. With this focus the current research project is more related to the interactional communication related to feedback and two-way communication processes.

The focus of the Collaborative Design scene in the training is to encourage and stimulate the involved practitioners to interact and exchange task based knowledge and to support this with a Design Support Tool and not on training the practitioners on the skills of communication and all the socio-emotional variables related to these skills. Although what is of interest for the practitioners that they are aware of each other educational and professional backgrounds and use this awareness to introduce messages to result in additional and complement task based knowledge for an integral design as feedback. This basic awareness and related skills needed for face-to-face scenes can be

addressed as basis necessary to work in a collaborative scene for group or inter-group communication within organizations or inter-organizational.

Because of this focus of the current research project the communication model of Feldberg (1975) with its specific characteristics gives an appropriate representation. The communication model of Feldberg (1975) is presented in Figure 1.

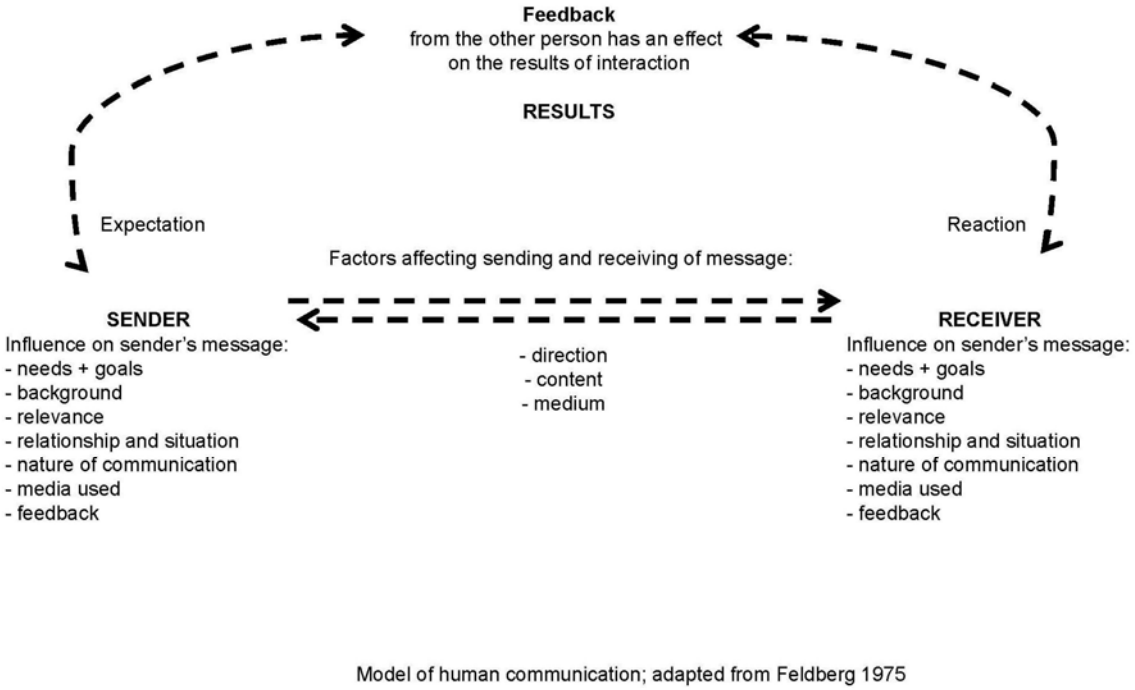


Figure 1 Communication model; adapted from Feldberg (1975).

The communication model of Feldberg can be explained as follows. First step is to look at the interpersonal communication process of two participants performing as the sender or receiver of signals and messages. Identified components are: sender and receiver; the message communicated, the medium used, the participant's expectations, their reaction to the message or signal, the result, direction of the message and the content. The degrees to which expectations of the sender conform to the reaction are related to direction of communication, task based content and the used medium. Communication is initiated by the sender to challenge and extend the knowledge of the receiver.

The second step is related to feedback. By adding a feedback loop from receiver to sender, he shows that the roles of sender and receiver are interchangeable. The feedback is a new message that is send by the receiver. What is of importance is the result of this feedback for the sender and receiver as well as for Integral Design. Although Design communication fits in this communication model, it shows to be more extended using various communication means for sending and receiving. Design information can be send from sender to receiver face-to-face on paper (using an image, sketch or drawing) together with an oral message, and the feedback of the receiver can be send back orally by speech or by paper (also in form of an image, sketch or a drawing) or by using both means. This research project therefore observes the results of communication between a sender and receiver both by speech and on paper in the form of notated artifacts of the design (design output). This feedback is considered to be part of the field of experience (knowledge exchange) of the receiver. It is assumed in this research project that such a face-to-face setting with these characteristics stimulates interaction and knowledge-exchange between practitioners. The results of the interaction and knowledge

exchange between sender and receiver is part of the Collaborative Design process to develop and produce an Integral Design.

LEVELS OF COMMUNICATION

Kreps (1989) complemented with Emmitt and Gorse (2003), distinguishes the following levels of communication:
- Intrapersonal communication: only one person involved, internal processes that enable individuals to process and interpret information
- Interpersonal communication: between two people involved, in order that a person can establish and maintain relationships; the message is intended only for one receiver.
- Small-group communication: more than two people communicating to allow them to co-ordinate activities.
- Multi-group communication: different work-groups communicating to each other; a number of groups or sub-groups involved; messages are largely contained within the specific groups.
- Mass-communication: sent through media with little control of who and how many receive the message; groups can be targeted (Emmitt and Gorse 2003).

The current research project focuses on Interpersonal communication between two practitioners in a Collaborative Design scene. This to determine and compare as clearly as possible in different scenes the interaction and knowledge exchange between the involved practitioner-types for such Collaborative Design scene from design and construct.

SCENES AND RICHNESS OF COMMUNICATION

There are several scenes for Collaborative Design. The available scenes are synchronous and asynchronous Collaborative Design scenes, related to time and place relation. With the development of the complexity of design tasks and its organization many different communication scenes are available and used. As stated in the introduction of this chapter ‘effective’ communication in the Collaborative Design Team is necessary. Related to Collaborative Design scenes it is concluded that in this research project, workshops, as a specific type of formal team meeting, are appropriate to use. With this requirement the scene of communication should be a scene using the same place and time; synchronous communication.

In other communication scenes many different types of communication-support or communication media are used and needed. Daft and Lengel (1984) developed a theory which is based on a hierarchy of information richness of the commonly available media. They use four criteria for ranking:
- Availability of instant feedback
- Capacity of the medium to transmit multiple cues such as body language, voice tone and inflection
- Use of natural language
- Personal focus of the medium.

Their argument is that team performance improves when team members use media with higher information richness. In this ranking, synchronous communication is ranked higher than asynchronous communication. Thus dialogues and meetings with face-to-face communication should be the best medium for exchanging meaning for a shared understanding within a team. This is stated by research on preference for interpersonal communication by Gorse (2002) and den Otter (2005). Therefore the most optimal Collaborative Design scene related to the focus of this research project should be organized as synchronous scene for face-to-face communication.

Communication support tools which are used in face-to-face scenes by practitioners are mostly sketches and images, because they are commonly used to communicate design ideas and concepts (Bates 2008), although verbal explanation is necessary to derive the right understanding (Lawson 1994). When considering the Collaborative Design scene with practitioners with different educational

background, not all practitioners have the expertise and skills to use these communication tools in an equal or same manner. The Collaborative Design scene for this research project therefore aims to support both type of practitioners with a communication support tool.

In general the following requirements for such support tool are needed for interaction between individuals (Lindemann et al. 2003). Methods used should:
- Be flexible and adaptable
- Be easy to learn and use
- Have a clear benefit / effort ratio
- Be dedicated to a concrete field of application (goal, restriction, limitations),
- Identify performance and critical factors
- Support convergent-divergent thinking
- Support communication with the goal of consensus finding
- Support the visualization of mental ideas and images
- Be able to structure and group topics, ideas, solution, problems
- Critically reflect team work, results and solutions,

Scenes of communication must be understood within the environment in which the communication takes place (Dretske 1999). The specific environment will influence the interaction (Newcomb 1953; Bales 1976; Gorse 2002). As stated before in design and construction projects are many different phases and variables of interaction between practitioners. To get insight into the practical situation for Collaborative Design is was shown that these scenes are sparse in practice and, related to the variables, not easy to organize in a comparable way for both support and training. This is especially important when this Collaborative Design scene is needed for research purposes to collect reliable data. It was also discussed that workshops with a synchronous communication scene is the most optimal scene to use for Collaborative Design in the current research project. The focus in this specific Collaborative Design scene is on task-based interpersonal communication.

RESEARCH ON COMMUNICATION

First type of research on communication and interaction is related to the actors involved. (Kleinsmann et al. 2005; Kleinsmann et al. 2007; Visser 2007). The following main characteristics are pointed out:
- Actors from different disciplines use different jargon
- Actors from different disciplines use different methods to represent the design
- Actors from different disciplines use different levels of abstraction

Additionally to the use of these characteristics when observing interaction, these characteristics are also important when developing design support.

Further studies on aspects and effects of communication in multidisciplinary teams (Majumder 1994, Eastman 1996; Gabriel and Maher 1999; Ahmed et al. 1999; Boujut and Laureilard 2002; den Otter 2005; Zha and Du 2006; Emmit and Gorse 2007; Holzer 2009). Due to interdependency between the actors (Latour 1987) knowledge exchange and sharing is needed that is showed in their interpersonal communication using preferred communication tools (Emmitt et al. 2008). Most of the research focuses on enabling technologies that could assist designers to collaborate, coordinate and make decisions during Collaborative Design (Eastman 1996,1999; Boujut and Laureilard 2002; den Otter 2005; Zha and Du 2006). Other studies focus on how to capture communication in Collaborative Design (Tang and Leifer 1991; Ahmed et al. 1999; Gabriel and Maher 1999; Grieb and Lindemann 2005; Emmitt and Gorse 2007; Emmitt and den Otter 2008).

Important research related to interaction in Collaborative Design Teams is on how to observe and analyze these teams. First aspect of observing teams is to have bona fide groups (Gorse 2002). There are two main aspects related to group communication, First; social interaction is essential for building and maintaining relationship and Second; task-based interaction is necessary to accomplish the group goal (Keyton 1999). This is also confirmed related to the success of projects in the Building Industry (Gorse 2002; Gorse and Emmitt 2007). Most difficult is to observe, capture and understand the socio-emotional and task-based interaction in practice. This is difficult because of the difficulties to separate the various variables that are part of communication behaviour such as e.g.; context, intonation and speed and type of human interaction. Because of the difficulties for capturing meaningful data and the extent of observation and the method of collecting data this gives limitations to the level of observation (written or video) with research with the focus on socio-emotional communication such as applied by Gorse and Emmitt (2003) and a limited amount of research projects on communication in live project to collect comparable data. However, as stated before the focus of this research project is on task-based interaction and therefore it is important to use observation methods which can give insight in the interaction and knowledge exchange of task-based feedback results of the involved practitioners.

On the subject of observing and analyzing interaction there is research on a broader field of research (Bakeman and Gottman 1986; Emmison and Smith 2000; Van Leeuwen and Jewitt 2001) as well as on the field of design in product and buildings observing and analyzing (Stempfle and Badke-Schaub 2002; Kleinsmann et al. 2005; Pektaş and Pultar 2006; Gorse and Emmitt 2007; Mc. Donnell and Lloyd 2009). For the research on the field of design in product and buildings much research uses video-recordings and protocol analysis and is focused on social-emotional interaction.

Gorse and Emmitt (2003) studied the usefulness of research tools and their strengths and limitations collected from student groups in a relatively controlled environment and a review of doctoral studies. For the studied aspects they give the following remarks that, First; there are variations in quality and detail, which may compromise the validity of the data, Second; the use of video transcripts and complicated classification systems (IPA, SYMLOG) need considerable instruction on how to apply and use as a method, Third; the influence of the own interpretations researcher(s), Fourth; the coding for analysis are not part of the original data. Fifth; important is how and what data are recorded, Sixth; rules for transcription need to be made before starting, Seventh; studying methodologies in advance is needed.

When reviewing the aspects and research related to interaction it can be concluded that most research is done mainly with the use of video-recordings and mainly on socio-emotional communication which use parts of the recorded scenes to analyze and determine tendencies for socio-emotional aspects. Because for into task-based communication it is necessary to have a fine-grained picture of the task-based feedback results by the interaction and exchange of knowledge it is necessary to use written as well as video-recorded results of the total Collaborative Design process. A possible reason of less research on task based communication with video-recordings therefore could be the time-consuming aspect of analyzing these results. The necessary use of video-recordings implies a careful way to use them related to the privacy of the practitioners involved in the Collaborative Design scene (Hugill 1999) and the management of the data of the recordings.

For reflection and retrospective on the observed communication on task-based interaction, knowledge exchange and the influence of the Design Support Tool is two-sided. First reflection by the researcher directly should be avoided, the use of assistants could be a help to record the reflections. Second, the related to the reflections of the involved participants could be problematic due to emotional aspects (Loosemore 1998). Based on the overview and results by Gorse (2009) for appropriate observation methods for task-based research on communication, this should be a combination of the results on content as identification of these results related to the sender and receiver of the interaction and knowledge exchange. This could be determined most optimal by use of video-data and quantifying

communication acts of sender and receiver. A possible other method could be Bales IPA (1976) because with this method discussions can be viewed as different categories or just one category of communication and it is a standardized and recognized method compared to other research.

Related to the communication scenes the most researched communication scenes are those consisting of groups in the design-phase or in the construction-phase. When related to the design-phase the following communication scenes are viewed, First; only practitioners with design experience and expertise (eg. Architects and consultants HVAC, Constructional Engineering), Second; practitioners with design experience and expertise and clients or users. Related to the construction-phase are viewed practitioners with different educational background such as Architects and Contractors or Sub-Contractors. As far as known there are no observations and analyzes of communication scenes for the design phase were Architects and Contractors or Sub-Contractors are collaborating with the focus on task-based communication. For Collaborative Design scenes as defined for the current research project there are no examples, data or research results available.

1.3 KNOWLEDGE AND COLLABORATIVE DESIGN PROCESSES

Two main categories for knowledge can be defined: explicit and implicit-knowledge. Explicit Knowledge is defined as: easy to communicate while 'manifest' and captured / codified through representation (Brereton 1998; Goldschmidt & Porter 2004) into language, formulas, procedures and manuals. Implicit- or Tacit- Knowledge is defined as: personalized knowledge which is stored in the heads of the human being and hard to communicate (Nonaka 1999, pp. 10; Polanyi 1966). These categories of knowledge can be situated as context specific and related to; personal experience, insights, reflections and logical reasoning coupled to social values, religion, cultural heritage and gender.

KNOWLEDGE AND EXPERTISE

Knowledge levels are related to the studies of expert behavior. These studies are founded on how experts process information, and how domain-specific knowledge is represented during the problem solving. There is considerable evidence about differences between novices and experts in knowledge representation; it's processing and the way that knowledge is used. Expert performances have been studied in many different domains and different scientific approaches have been used to investigate outstanding performances (Ericsson et al. 2006; Ericsson and Smith 1991; Feltovic et al. 1997). There are diversities observed in experts' performances which are elaborated by Ericsson and Smith (1991). Ericsson and Smith reviewed the approaches in expertise research with an emphasis on different approaches undertaken in expertise domains. Shen and Liu (2003) identified the level of professional experience, the design experience and the personalities of the team members and to whether the team is sufficiently multi-disciplined as one of the characteristics for Collaborative Design scenes..

In the context of design, expertise is 'understood as possession of a body of knowledge and the creative and analytical ability to extract, analyze and apply relevant knowledge' (Popovic 2004). Expertise is related to: attitude, knowledge and skills. Expertise needed for a specific job and or task needs competence and is the basis for performance within a team, group or organization. When related to a specific job or task, beside of attitude, is related to one or more knowledge domains and development of knowledge by learning.

EXPERTISE AND COMPETENCE-PROFILES

Competence profiles assist in effective learning and development by identifying the attitude, knowledge, skills and abilities that are necessary for successful performance in a job. Organizations typically include incremental competence profiles scales as part of the overall competence structure. These scales reflect the amount of proficiency typically required by the organization within a competency area; related to roles, education and context (Dubois and Rothwell 2000; Shandler 2000).

COMPETENCE AND THE BUILDING INDUSTRY: DEVELOPMENT AND RESEARCH

When related to the complexity of common design problems and knowledge, Kalay (1997) points out that projects in the building industry differ from those in other industries such as aerospace- and car-industry due to the fact that each project is unique while related to a unique context. Architectural design often deals with the unknown where problems are defined and solved concurrently while designing and during construction. In this context as argued by Kalay (1997) and Kvan (1997, 2000, 2006) the collaboration between Architects, engineers, contactors and owners is difficult. This because each group has different world views and use different levels of abstraction to work on the problem at hand. Specialists such as engineers and Contractors apply a world view dependent on precise problem and goal definitions before they can start to search for solutions. Architects apply a mode of practice through discovery (Kalay 1997). Were the specialist is tending to a more unified strategy which could be applied in detail *(how)* the Architect tends to a more holistic strategy *(what)* which is context specific, multi-dimensional and interactive (Lawson 2002). Whereas the Architect has to interact and to collaborate with the other practitioner-types there is an increase importance in the interaction between the individual and the group to fine-tune the level of detail of information that can be deal with as a group as well as the definition of common design goals and priorities (Moum, 2006). This is in line with the arguments of Schön and Wiggens (1992) and Achten (2002) to apply engineering knowledge in the early stage of the design. Achten (2002) and Pulsifer (2008) use the terms of Architecture and engineering related to knowledge. They use the engineering knowledge related to engineering-advisors involved in the design-process and educated in the academic world and with design-experience.

To understand knowledge in the context of design it is necessary to study produced and captured during the design process. In a broader perspective of design Vijaykumar and Chakrabarti (2007)) studied the types of knowledge produced as well as what portion of the produced knowledge is captured in formal documents. The taxonomy has four categories of knowledge. These are: topics (issues and proposals, information and knowledge, new and old), classes (product- and process-based, requirement, requirement-problem, solution, method, feature, manufacturing and location), activities (problem understanding and problem solving, generate, evaluate and select) and types of questions (descriptive; answer is elaborate, point; answer can be yes or no, etc.). In brief these studies showed that designers captured mainly for generating of proposals and on what they designed and not how. Designers focus in general on the structure of the designer artifact and not on the behavior and function; they focus on problem-solving related rather than problem understanding. Most knowledge created is related to generation rather than evaluation and selection stages and mostly documented in point based answers. What is interesting about these results is the tendency that most of the documented knowledge is about the *what* of the artifact and less about the *why* and *how.* Although this gives an insight into the single categories the relationships between these categories are not clear. When discussing collaboration between practitioners with different educational background and knowledge of design and construct, the focus should be on the possibility for the involved practitioners to interact and share knowledge about the *what* and *how,* the Contractor and the Architecture-related knowledge.

Where Achten (2002) and Pulsifer (2005) use the engineering knowledge they discuss the situation of the traditional design team where the engineer-advisor and Architect collaborate in a design team. Both have the same educational background as academics, although there world-view differs; they both have experience in design. When discussing the Collaborative Design scene were Architect and Contractor are working on a design task the practitioners differ in educational background.

In his studies about valid knowledge for the professional design van Aken (2005) describes the increasing complexity for the design and the separation of designing and making related to the consequences for a more professional approach. Partly based on Bunge (1966) van Aken distinguishes the object-, realization- and process-design coupled with the necessary object-, realization- and process-knowledge for the professionals involved. Here the senior designer uses his/her repertoire of general design knowledge (Schön 1983), based on formal education and through learning on the job.

Van Aken defines the following:
- Object-knowledge: knowledge on the characteristics and properties of artifacts and their materials (van Aken 2005, page 388). Design knowledge is for this research project the equivalent of object knowledge
- Realization-knowledge: knowledge on the various physical processes to be used to realize designed artifacts (van Aken 2005, page 388). Knowledge about how to execute / built / construct the sub-solution(s) within a specific design task.
The definitions used by Van Aken are most appropriate to the current research project, because they relate most specific to the different types of knowledge which is necessary for the Integral Design as defined.

KNOWLEDGE EXCHANGE IN PRACTICE OF THE BUILDING INDUSTRY

The focus in literature about knowledge-exchange is within the field of business-management and coordination (Simon 1991; Cook and Brown 1999; Barnett 2000; Parker 2002; Orlikowski 2002). There is less literature about knowledge-exchange in the Building Industry is (Holzer 2009).

The topic of knowledge-exchange in multi-disciplinary design collaboration within the Building Industry is not only addressed in theory but also in practice. The Buildings Systems Integration Handbook (AIA 1986) set the standards for systems integration across multiple disciplines. One of the international examples is the Plan of Work of the Royal Institute of British Architects RIBA (2008) which lists services that need to be provided by practitioners according to varying contractual frameworks. However, these guidelines give little insight on *how* the interaction takes place and *how* information is handed over in everyday practice.

Related to the education and training of practitioners in the Building Industry internationally as well in the Dutch situation organizational bodies like the AIA, RIBA or BNA make efforts to educate members of the building professions in matters regarding design collaboration. However, within the restrictions of this research project there is no evidence of research about design-collaboration across disciplines occurring within practice. Although, there are reports of Architecture and engineering of successful collaboration on building projects (Addis 1994; Otto and Rausch 1995; Holgate 1997; Brown 2001; Sasaki 2005; Balmond and Yoshida 2006), but not of shared efforts between companies who search to improve their collaborative methods. A possible reason for this absence of found research and literature could be two folded. First; part of the research in this field is done by commercial research organizations which would not like to share these results because these are part of their commercial existence. Second; research output could be related to intellectual property (IP) issues and the wish of those involved to use research outcomes for gaining market advantage. Summarizing the previous paragraphs it can be stated that in this research project the focus is on task based interaction and

knowledge exchange of object- and realization-knowledge as defined by van Aken (2005, page 388) between practitioners with different educational background, in a stimulating Collaborative Design setting as design support, working on a complex task to develop an Integral Design.

1.4 FOCUS OF COLLABORATIVE DESIGN PROCESSES IN THIS RESEARCH PROJECT

Clarity of design support should provide the right conditions for the practitioners involved, the setting for cooperation and the availability and exchange of knowledge to link design and realization. Because many different aspects influence the success of Collaborative Design, it is important to pose restrictions on the research focus. A restricted focus is needed to organize a setting to observe the interaction and exchange of knowledge that links design and realization, and to exclude other aspects.

Due to its increased importance to the overall sustainable building design, the roof was considered an interesting focus to study Collaborative Design. Roofs are now an ever more important location for the placement of 'innovative' renewable energy systems and sub solutions to improve the performance and sustainability of buildings. However, despite the growing importance of the roof to the building design, there is little history of Collaborative Design teams working together to provide robust and Integral Designs for roofs.

In contrast to the development of the design and engineering for façades, the collaborative development of roof designs is lagging behind (Kragh 2009). To date the technological and process-development of the roof as a part of the total building has been overshadowed by the façade for a number of reasons. First, compared with the roof the façade is usually still Architecturally more attractive to many clients and Architects. The Architectural value means that facades are given more importance and investment than roofs. Second, because of the different new functions of the façade related to comfort-systems and possibilities in material and construction, the façade has become much more complex. The design, engineering and realization of façades therefore required more practitioners from different disciplines. During the last decades of the 20th century Engineers and Contractors worked on their competences and skills to fulfil these new requirements. Step by step the façade-industry became an integral part of the multidisciplinary design and engineering of complex façades as part of the total building.

The roof also increasingly became a key building part for technical equipment related to new energy and comfort-systems facilitating the total building. The roof now hosts an increasingly large array of new roof products which provide energy and comfort management for the building. A few examples of these relatively new products include photo voltaic-panels, solar-collectors, ventilation systems, roof lights, antennas and safety-systems. Through these influences the roof is handled more often as the 5th façade in content and as a coherent part of the building-design. However, as in the façade-industry, it takes time to organize the roof-industry, because it is also highly fragmented. The new products and the different practitioners that regulate, produce and install these items increase the complexity of design and construction. This implies an increasing chance of practical problems, safety issues or even accidents and failure costs.

The complexity of the roof as part of the building and building installations in and on the building has led to new design and construction tasks. The roots of all these task-related problems are as diverse as aspects within the total spectrum of design and construction of the Building Industry. On the one-hand, there are often design faults and wrong construction-optimization, as has been noted in flat roofs (Kool 2003). On the other hand, roofers don't have the means and / or knowledge and skills to act in the process of development of the construction plan or to judge on the quality of new products because of insufficient product-information and standardized criteria (Jablonska 2005). This leads to

damage to buildings through leakages, condensation and wind. The failure costs related to these items are approximately two billion Euros a year within the European Union (Euractive Roofer 2005).

Besides practical construction aspects, the Building Industry has to cope with the change of responsibilities and changing definition of tasks. The role of the main Contractor is changing towards that of manager and coordinator, which means that sub-Contractors are becoming more responsible for their work and are changing the collaboration between established practitioners (USP 2008). Working with this mix of different practitioners, transparency of responsibilities is necessary to decrease the failure costs and to work effectively on the new designs. This change will also ultimately lead to the sub-Contractor being contracted not only on price in the short term, but in the long term also on the quality of work performed and on the strength of the long-term working partnership. HVAC-installers and advisors (57%) as well as the majority of the Contractors (50%) think that these partnerships will evolve in the future (USP 2008). The position of the sub-Contractor in the design- and building process will therefore possibly change to a more collaborative one with practitioners in an earlier stage of these processes.

Simultaneously, there is a growing awareness within the different construction sectors, especially within more traditional sectors such as the roofing-industry, for the necessity of product- and process improvement. This requires an upgrade in knowledge and skills and the organization of strategic alliances in order to come up with more competitive offers for tenders and better organization of construction-teams (Geurts & Borsboom 2002, 2003; Slob 2003; Dakmeester 2005; HBA 2005). From a broader perspective, the roofing-industry is also working on improving roof-concepts and competences on a technical manner on the European level (Euractive Roofer 2005, 2008). Related to the design of the environment this requires improvement of knowledge and skills of working in multidisciplinary teams. The described situation shows that there is a need for competent practitioners. Training of Collaborative Design Teams is a response to fulfill this need because working on interaction and knowledge exchange for roof-improvement is also rare.

ARGUMENTATION AND FOCUS OF COLLABORATIVE DESIGN TEAM AND BUILDING-COMPONENT

One important effect of these changes is that many small, multidisciplinary teams are required to work on a part of a design task, which ultimately must fit into the total design being worked on. The Architect in most cases will be part of such a design team, each time with different practitioners from different knowledge domains throughout the process. Related to the team-structure for the roof-design in a team-setting, the most compact team should consist of a designer with object-knowledge and a practitioner with realization-knowledge. The main representative for the design is the Architect. For the roof-part the roofer and installer are the two most important Contractors working on the roof.

A structured and methodical way of working and notating by the involved practitioners related to a specific component of an integral design, in this case the roof, is essential for interaction and knowledge exchange. To reduce the complexity, in a Collaborative Design setting the practitioners usually concentrate on the component part of a design task. A structured way of working and notating in such a setting is also important to share own knowledge with knowledge of the other teams involved in the design-process. Related to the category of knowledge this implies that for the current research project the focus is on explicitly notated object- and realization-knowledge. This focus is for the following reasons. First; to interact and exchange knowledge within the Collaborative Design process effectively, the notated items are the items both practitioners of the Collaborative Design Team can refer to, discuss and develop. Second; because in the practice setting more Collaborative Design Teams can be involved to work simultaneously or successively on an Integral Design the explicit notated knowledge is necessary to interact and exchange knowledge among these teams.

So, a Collaborative Design setting organizes key-components for an Integral Design in a coherent way using the most compact design teams with different educational background. Such a setting needs practitioners having object-knowledge and also ones having realization-knowledge. All practitioners need to interact and exchange their specific knowledge in order to effectively work on a part of the Integral Design. In the case of designing the roof as specific part of the total building, the practitioners are Architects and Contractors, where the Architects have a scientific educational background (WO) and the Contractors a middle or higher professional educational background (MBO, HBO). One of the characteristics of practitioners with a WO-background is that they are educated to think and work on a higher abstraction-level which is related to object-knowledge. Complementary, practitioners with a MBO or HBO-level are educated to think and work on lower abstraction-levels which need realization-knowledge.

In this research project the fields of experience are related to the object-knowledge of the Architect and the realization-knowledge of the Contractor collaborating in a design team. It is assumed in this research project that such a face-to-face Collaborative Design scene, a Workshop, with these characteristics stimulates interaction and knowledge-exchange between practitioners.

Although a solution of a design task is context specific, the requirements of the design task, e.g. for the roof as part of the total building are related to a broader set of items. These set of items can be defined as function-types; relevant items that must be incorporated in the product for the design task, or essential items that the design has to fulfill. Function-types represent items of object- and realization-knowledge. Type of knowledge is again related to type of competence of the different practitioners. Competence profiles capture the expected type of knowledge related to a specific type of professional.

These function-types are the aspects necessary to realize the Integral Design. Related to roof-design, the function-types water-proof, temperature-proof and construction (robustness) are some examples of function-types. However, because the roof-design is part of the Integral Design, the design should also incorporate more general function-types related to e.g. Architecture and Sustainable Energy generation. The focus in this research project is on function-types as part of knowledge-types in the way van Aken (2005) defined.

1.5 PROBLEM DEFINITION, AIMS AND OBJECTIVES

Based on the preceding explanation the Problem Definition for this research project is formulated as follows: there is a lack in practice of Collaborative Design scenes were practitioners – Architects and Contractors – can interact and exchange object- and realization-knowledge working on design tasks to produce Integral Designs that comprise realization-knowledge.

The main Goal of this research project is to develop and test a Technological Design: a Collaborative Design Workshop with a Practice Setting to observe and stimulate interaction and knowledge exchange, between an Architect and a Contractor. They need to work as a Collaborative Design Team on a complex Design Task of a design for a roof supported by the application of a Design Support Tool. It is assumed that such application stimulates interaction and knowledge exchange by its users.
In order to develop such a Technological Design, three aims are formulated.

- The first aim is to investigate how the knowledge of both practitioners is introduced and shared in a Collaborative Design Workshop. This investigation will provide insight into the available knowledge from these practitioners and how they collaborate to exchange such knowledge.
- The second aim is that this Collaborative Design Workshop should facilitate a methodical introduction for knowledge exchange between the involved practitioners in the conceptual phase for roof design. A key consideration is to determine a suitable collaborative setting in which the

practitioners can interact productively in order to exchange the contributed knowledge, specifically object- and realization-knowledge.
- The third aim is to test whether the application of the Technological Design, by the practitioners, stimulates the Integral Design for roofs by the contribution of realization knowledge.

The objectives for this research project are gained insight in:
- Interpersonal Explicit Interaction and Task-based knowledge exchange in Collaborative Design Teams between practitioners with different educational background from design and construct working on Collaborative Design of roof as building component to realize an Integral Design
- Influence of use of specific Design Support Tool related to interpersonal Explicit Interaction and Task-based knowledge exchange in Collaborative Design Teams between practitioners with different educational background from design and construct working on Collaborative Design of roof as building component to realize an Integral Design
Complementary to these objectives is the following objective:
- To develop a method as design support to observe explicit interpersonal interaction and knowledge exchange and the effective use of a specific Design Support Tool by practitioners with different educational background in a Collaborative Design Scene to realize Integral Designs for roofs.

1.6 THESIS OUTLINE

This thesis is structured as follows. Chapter 2 explains the theoretical framework used for this research project. In this Chapter it is explained why and how the DRM is used to frame the overall research project and how the development of the Collaborative Design Workshop with its formats is framed.

Chapter 3, the main Chapter of the thesis, presents the results of the four DRM research stages. Subsequently the outcomes of each research stage are presented and explained. First, this concerns the outcomes of the Research Clarification and the Descriptive Study 1, which are the basic input for the research in the third DRM stage: the Prescriptive Study. Also based on the outcomes of the thirst and second stage Research Questions and Hypotheses are formulated. In the third stage five workshop series are executed to investigate and develop iteratively the workshop setting and its key-components. Subsequently the outcomes of each workshop series are presented and explained which implies also research improvements in terms of observation and analyzing formats. Next, the outcomes of the prescriptive study concerns the concept for the Technological Design presented as a Collaborative Design Workshop and its key-components. Finally the outcomes of the fourth DRM stage: Descriptive Study 2 are presented and explained. This concerns the Technological Design: the Collaborative Design Workshop with its key-components and observation and analyzing formats and the answers to Research Questions and hypotheses.

Chapter 4 presents the conclusions, reflection and recommendations. The conclusions are reflected to the aims of the research project. Based on the conclusions the Hypotheses are confirmed or denied referring to the Measurable Success Criteria. The reflection on the outcomes of the research project concerns two parts. Part one reflects on the outcome *in* the research project; the results of the use of the key-components in the Definitive Collaborative Design Workshop. Part two reflects on the outcomes *of* the research project and the tests of the Definitive Collaborative Design Workshop and the developed observation formats. Chapter 4 concludes with recommendations for future research. Chapters 5 and 6 present the references and appendices respectively.

2 RESEARCH STRATEGY AND METHODOLOGY

This research project focuses on an urgent Collaborative Design process problem in practice situations in the Dutch Building Industry. Because, as explained in Chapter 1, a lack in practice of Collaborative Design scenes occurs where practitioners – architects and contractors – can interact and exchange object- and realization-knowledge working on design tasks to produce Integral Designs that comprise realization knowledge.

To develop a solid and validated answer to the problem formulated, in this Chapter the research Design and methodology are described and explained. The problem described is a wicked problem occurring during design practice and is still vague and complex due to the fact that many variables are involved in such a scene that cannot easily be distinguished and appointed.

2.1 RESEARCH STRATEGY

Based on the findings of the literature study of chapter 1 and additional reference of Weggeman (2001) it can be concluded that the research project concerns an empirical study. For empirical research three types of research can be discriminated (Weggeman 2001, page 18), First; a qualitative approach that addresses the exploration and description, Second; a quantitative research which addresses the explanation and prediction, and Third; a qualitative research that addresses mainly the explanation, prediction and prescription. The Third type of research works with a problem definition / design objective. This type of research points to Case Study Research or an Iterative Design (action research) as used in Medical Science, Justice or Architecture. This research project can be defined as the third type of research: a qualitative research that addresses the explanation, prediction and prescription because this research project studies '*why, what* and *how'* questions for which case studies are appropriate as Yin (2003) explains. Regarding the Problem Definition observing a lack in practice of Collaborative Design scenes' and the objectives formulated a multiple Case Study Research approach is needed in the first place. This approach allows getting a proper insight in the research problem, to be able to formulate the appropriate Research Questions based on comparison of the outcomes of the analyses of the multiple cases. However such research is not sufficient to reach the proposed objective: the formulation of a model to stimulate interaction and knowledge exchange between practitioners. For that part of the research a semi-experimental design is needed as Campbell (1971) explains because it is appropriate to provide answers to Research Questions. These semi-experiments or workshops allow focusing the research, by only studying an aspect or part of the design process, comparing different teams working on the same problem. This method of protocol study in laboratory conditions or workshops (Macmillan et al. 2000; Austin et al. 2001) for design research offer detailed information about design activities and comparing different teams working on the same design task; as needed in this research project. These semi-experiments are organized by using experimental groups that are stimulated in a collaborative design scene to execute a design task by using a Design Support Tool and compare the results to these of a control group without using a Design Support Tool in executing a design task. In an organizational context of a workshop setting the strict implementation of this principle is possible without disturbing the social aspects of such scenery.

For the type of research and the research strategy as described a suitable research methodology is needed. Methodology can be defined as 'a compatible collection of assumptions and goals underlying methods, the methods, and the way the results of carrying the methods out are interpreted and evaluated' (Reich 1995, page 211). This research methodology needs to be flexible and to has to allow iterations based on gained insights of a research phase to be able to improve in a methodological way the methods and tools used for the research in the next phase. First the research problem need to be framed and decomposes to a number of Research Questions focusing on each of

the variables to be studied in the next part of the research in which various experimental and control groups are observed and analyzed in design practice situations executing design tasks.

2.2 RESEARCH METHODOLOGY

On the basis of the research strategy described above the Design Research methodology (DRM) is chosen as the most suitable one. This methodology is a transparent and systematic framework that is able the best to first explore and frame the problem and than focusing to collaborative teams to study the problem in more detail. This methodology also allows the development of a Technological Design for design support.

The main reason for the development of a specific Design research methodology was that Design Research did not have its own research methods and research approaches needed, because approaches and methods from other disciplines could not be applied directly for design research. That situation made it very difficult to compare different aspects and examples from areas of design research. With this Goal in mind Blessing worked on an approach, a research methodology for design research, based on a shared understanding and agreement from the main international experts related to the different fields of knowledge. This research methodology was developed by Blessing (Blessing 2002) and Chakrabarti and finally presented in 2009 as the Design Research Methodology (Blessing and Chakrabarti 2009). The Design Research Methodology (DRM) can be seen as a generic design research methodology that fits different research areas and provides a framework that addresses and connects Research Questions and related methods and research improvements in a systematic way by framing them in separate stages. The DRM is most suitable for this type of research project compared to others like the research framework developed by Duffy and O'Donnell (1998) and the Soft Systems Methodology (SSM) developed by Checkland (1981, 1999).

Other important reasons for selecting the DRM are: First, DRM forces the researcher to carefully decompose the research process into research stages. Once this is done, the researcher has a clear basis to work out what steps are necessary to fulfill the Goals of each of the subsequent research stages. In effect, this approach forces the researcher to clearly account for the decisions taken throughout the research process. In addition, the assumptions that must be made by the researcher in each stage are developed and applied on the basis of Research Questions. Second, the answers to the Research Questions will be systematically fed back into research improvements, or not, depending on the outcomes of the analyses and reflection to the hypotheses formulated. The final reason for using the DRM is because it responds adequately to the description of the aims and objectives as formulated. The DRM-framework guides the researcher and structures the research project by imposing four clearly defined research stages. The final result of the DRM is the Technological Design.

Being a technical university, the TU/e allows for two possible types of PhD thesis: The first is a 'Proefschrift', translated in English to dissertation, and the second is a so called 'Proefontwerp', which translates as 'Technological Design'. This thesis follows the second option: Technological Design. The key difference between the two is that the former seeks to provide an academic analysis of (physical) phenomena, whereas the latter seeks to provide a proven, sound and solid solution to a need in practice.

One of the aims for the Technological Design is to organize a Collaborative Design Workshop as the basic need to produce an Integral Design. This is operationalized by observing if realization-knowledge is incorporated in the design and collecting the explicitly notated function-types. In the case of the current research project this is a roof-design as part of the total building design. It is not argued that the approach developed here automatically leads to Integral Designs for roofs. This can be motivated because of two aspects. First, practitioners need to adopt the Collaborative Design

Workshop and design is a complex activity in which many variables are at play. Secondly, the contributions of the team members need to be balanced to assure an Integral Design outcome because of the difference in knowledge types of the practitioners. However, by testing of the Collaborative Design Workshop developed it can by shown that this approach solves the problem formulated and to reduce the risk of repeating such problems.

Since the aim of the research project is the development of a Technological Design, internal and external validity needs to be established. External validity is related to the following aspects. First; the present study is restricted to a defined group of practitioners, experts in design and practice, whereas for example a psychological study aims to generalize findings to the general population based on the results of a "representative" sample of the population that was tested under experimental conditions. For that reason, external validity is of little concern. Second; testing of the developed Technological Design within the possibilities in time and resources of this research project by a third party was not possible.

Based on the research Goal, the Technological Design can be argued to be internally valid, if it can be demonstrated that the Collaborative Design Workshop does support interaction and exchange of realization knowledge between the practitioners. Since there is no baseline to measure from practice, the judgment about the interaction and such knowledge exchange that does occur, needs to be made based on the findings of series of semi-experimental workshops. The outcome of the Prescriptive Study: the so called: Definitive Collaborative Design Workshop was also tested in semi-experimental workshops in the Descriptive study. In this way the key-components and the analyzing formats were also tested. Finally the outcomes of the analyses could be compared to search for a tendency, a relationship or a connection in the observations and measurements.

2.3 DRM FRAMEWORK DETAILED

In this section the application the DRM framework and its consecutive stages as applied in this research project is described and explained in more detail as well as the DRM scenario that needs to be chosen. It needs to be noted that in DRM research applications the stages performed and the results that follow are inextricably linked. DRM is a research methodology based on iterations made during the stages. It starts with making assumptions in the first phase, the Research Clarification which are converted into Research Questions in the second stage, the Descriptive Study 1. Based on this starting point the main content of the DRM stages is presented in this section.

Starting from an assumption, two distinct possibilities arise: either the assumption is true, or false. If an assumption appears to be true, the research can move on to the next research steps, but in the latter case if an assumption should need to be revised as well as the research stage for which the question was designed. This process is executed and repeated when necessary, to arrive at a suitable answer to the question at hand. This process underscores the iterative process abilities of DRM research. These iterative process abilities of the DRM are schematically shown in Figure 2 and 3, on the next pages.

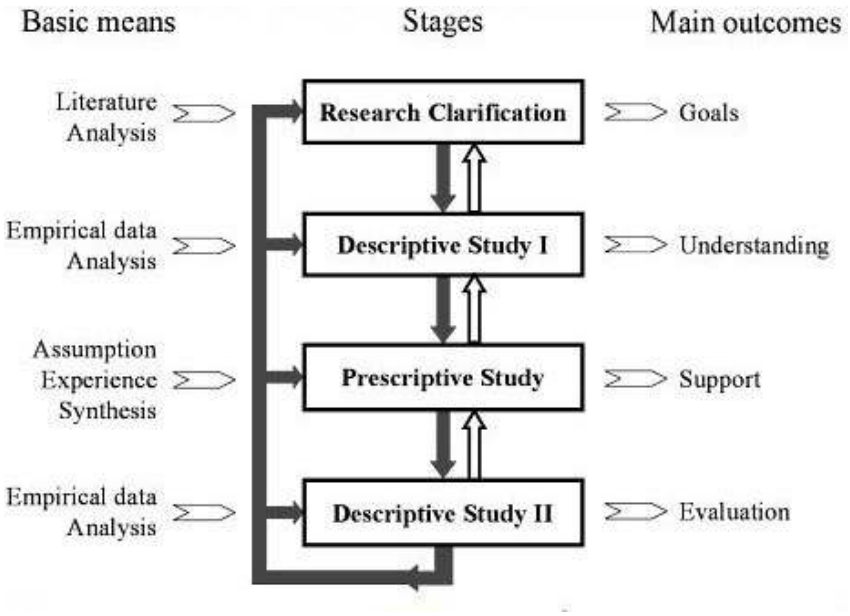


Figure 2 DRM frameworks (Blessing and Chakrabarti 2009).

2.3.1 DESCRIPTION AND APPLICATION OF THE DRM-STAGES

The first stage, the Research Clarification, has the aim to provide, in addition to the identified problem, clear Goals for the research. This is provided by formulating Hypotheses how to reach these Goals and which are the Measurable Success Criteria to identify if these Goals are reached.

The role of the Research Clarification is:
- To identify the problem, and the corresponding aims, the research is expected to fulfill in order to determine its focus; the aims are related to *why, what* and *how* questions.
- To support the determination in Descriptive Study I of the key-components that influences the success of the Collaborative Design Workshop
- To focus the Prescriptive Study of developing and improving the Collaborative Design Workshop as design support
- To enable evaluation of the developed Collaborative Design Workshop (Descriptive Study II)

In the Descriptive Study I, the main aim is to get the right understanding of the problem identified. This needs to be done by studying the current state of the problem in practice. Next the key-components necessary to improve the current state of the problem need to be formulated. Based on these key-components the success criteria that influence the problem are developed. This is done by developing additional Research Questions for the Prescriptive Study.

The Prescriptive Study, the third stage, has the aim to develop in a systematic way the design support. The second aim is to evaluate the design support. This development is executed in steps by applying research improvements – methods and formats – related to the key-components that affects the Collaborative Design Workshop. Such key-components were verified through answering the related Research Questions.

The fourth and final DRM-stage is the Descriptive Study II. The aim of this stage is to test whether the design support as developed does represent a solution to the problem formulated. The role of the Descriptive Study II is to test:
- Whether the design support and the key-components developed, can be used in a collaborative design scene.

- The application of the design support and its contribution to the integral design by using the developed Measurable Success Criteria.

It is important to point out that although the requirements of the DRM stages are clearly defined, the application of the stages can vary between different projects. Some projects may be able to or may choose to avoid a particular stage, depending on the nature of the problem and also the Goals of the project. For example, in some projects the problem may already be common knowledge within the field and in some other projects the main Goal may not be to provide a comprehensive solution. Some projects may move through the stages quickly, either because the problem is relatively easy to define or because suitable methods or formats to solve the problem are well known. Other projects, alternatively, may take much more thought, effort and develop research improvements that are suitable to deal with the identified problem. The accompanying table classifying the types of DRM research is presented in Figure 3.

The table in Figure 3 shows that DRM applications can be located on a sliding scale from 1 to 7, ranging from coarse grained applications at line 1 to fine grained applications at line 7. In addition, the authors of DRM point out, “It cannot be expected that each of the stages of the methodology will be executed in depth in every single project” (Blessing and Chakrabarti 2002).

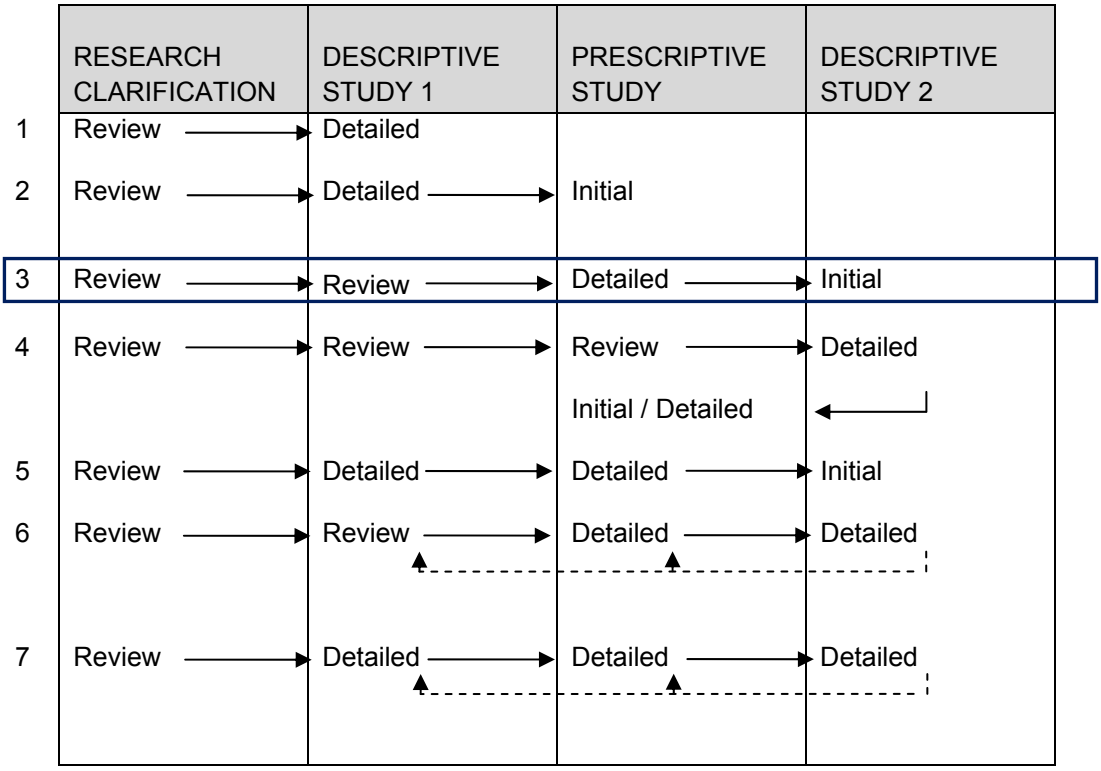


Figure 3 Scenarios for application of the four DRM stages (Blessing and Chakrabarti 2002).

Possibilities depend on iterative processes inherent to the DRM framework and allow both coarse and fine grained research variations.

The above explains the DRM methodology in general terms. Next will be explained how this research project is positioned in the scheme as Figure 3 shows, It is important to note that the lines 1 to 7 in the figure do not show any hierarchy. So, line 6 does not show a less or more important application of the DRM methodology. It simply illustrates the range of possible applications. It is also important to emphasize that DRM applications can be understood as being exploratory. It may not be clear at the outset, for example, if a research stage can be completed, or whether the findings of a particular stage will require the researcher to rework that or move to another stage.

This research project can best be positioned in line 3 of the scheme. This line represents the first DRM application that includes all DRM stages. The categorization of this research project follows the note of the authors of DRM, who point out that for a PhD research "the time and resources required are often underestimated and the projects mostly end as Types 2 and 3, respectively" (Blessing & Chakrabarti 2009, pp. 19). The basic reasons for this are limitations in time and other resources. Based on the above, it can be argued that "line 3" represents an ideal DRM application, in the sense that it describes a clear and linear process through the research stages. A "line 3" DRM application represents a method where the assumptions made in each research stage turned out to have been well made, without the need to repeat the stage because of unexpected results

Research Clarification is categorized as "review" in all DRM applications, as shown in Figure 3.

Descriptive Study 1 in the current research project is classified as "review" for two main reasons. First, much of the background research and motivation for the research project came from the previous work of the author and his colleagues at the BS research group of prof. W. Zeiler at the Technical University of Eindhoven concerning the research-field related to the current research project. As such, it was not considered as primary research within this particular research project, since it had been completed before the current research project began. Second, since the research aims to explore a Support for Collaborative Design teams, there was little possibility to conduct primary research into current applications of the method's use. What was possible, however, was to study Case Studies through analyses of management- and specific evaluation-reports of these Case Studies, and additionally review literature covering a range of aspects of the identified problem.

The Prescriptive Study is classified as "detailed". The reason for this is that a Collaborative Design Workshop will be developed as a semi-experiment and applied on real subjects in a suitable setting. In parallel to this process, formats for observation and analysis need to be developed to be able to conduct a measurable and adequate analysis of the results.

Descriptive Study 2 is classified as "initial". It is classified as such because the definitive Collaborative Design Workshop developed (DWS) is tested in practice with Architects and Contractors. Based on the testing of the design support, the answering of the Research Questions and the confirmation of the Hypotheses, the research project is closed according to the DRM methodology.

Finally the Technological Design and its protocol are presented and conclusions are drawn.

2.4. RESEARCH OVERVIEW, RESEARCH QUESTIONS AND GOALS

As explained before the problem formulated is a wicked and complex problem in practice that needs to be studied in detail to sharpen it first, to be able to formulate adequate Research Questions. In figure 4 an overview of the research per stage is showed with the corresponding Goals and the Research Questions showing in which stage these are developed and answered. Two Research Questions: RQ1 and RQ2 are studied in the first stage of the DRM research, based on literature review. These questions concern the type of knowledge that should be generated and when and how this should be exchanged in a collaborative design team. Based on the answers of RQ1 and RQ2 the Research Question 3 and 4 (RQ 3 -4) are developed. In the second stage: The Descriptive study, RQ3 and 4 are answered and the resting Research Questions RQ 5 to 9 were developed. In this way all Research Questions to cover this complex and wicked problem were developed. The Hypotheses and the Measurable Criteria, as the DRM research requires, are developed based on the answers of RQ1 and 2 in the first stage of the research. The overview as shown in Figure 4 is used in the next Chapter to provide a guide and summary per stage of the DRM. This overview is used in the next Chapter to provide a guide and summary per stage and sub-stage of the DRM. In the Prescriptive study, research

improvements are applied and these will be added to the overview to show the development during the research project.

	DRM Stage	Research Question(s)		Goals
1	**Research Clarification**	**RQ1**	*What type of knowledge should the competent architect, roofer and installer possess?*	Problem identification +answers RQ1-RQ2
		RQ2	*When and how should this knowledge ideally be exchanged within a Collaborative Design Team?*	Development of RQ3 and RQ4 Hypotheses and Measurable Success Criteria
2	**Descriptive Study 1**	**RQ3**	*What factors hindered the success of the case-study projects?*	Problem is expressed in practice Answers to RQ3+RQ4
		RQ4	*What are the necessary key-components of the technological design?*	Key-components identification Development of RQ -5-6-7-8-9
3	**Prescriptive Study**	**RQ5**	*Were the tasks sufficiently complex to require the collaboration between the practitioners?*	Pre-Answers to: RQ -5-6-7-8-9 Research Improvements
		RQ7	*Did the face-to-face setting provided by the workshop allows collaboration between the practitioners working on the design task?*	
		RQ6	*Did both types of practitioners succeed in contributing realizations knowledge?*	
		RQ8	*Did loose introduction of the Morphological Overview lead to acceptance of the tool by the practitioners?*	
		RQ9	*When used did the Morphological Overview stimulate for the exchange and structuring of knowledge between the practitioners?*	Development and application of the Collaborative Design Workshop lay-out Finalizing of Research improvements
4	**Descriptive Study 2**	**Test RQ 1-9**		Answers to: RQ5-6-7-8-9 Testing the Key-components and Research improvements in the Definitive Collaborative Design Workshop Verification of the Key-components and the analyzing tools Evaluation of the Hypotheses and Measurable Success Criteria

Figure 4 DRM-stages with corresponding Research Questions and Goals.

2.5 VOCABULARY OF TERMS

In order for the reader to follow the argumentation, a number of terms that appear frequently or are important to the research project must first be clearly understood. To this end, a vocabulary of terms is compiled. It is important to point out that many of the terms must be understood as working definitions for this research project. A lot of the terms used might differ in meaning outside the project. The need to define the working definitions arises to prevent ambiguity in terms and the number of meanings each term can have. Even while searching for definitions of quite specific, formal terms such as 'collaboration', one is confronted with a number of alternative descriptions. The key terms are presented below in a table alongside their working definitions (Figure 5).

ITEM	**WORKING DEFINITION**
Collaboration	When practitioners from different practitioners with different knowledge backgrounds work together on a design task, through structured exchange of knowledge between the different practitioners. *Structured: to order for the purpose to realize the design task within the early phase of the design*
Collaborative Design Workshop	The practice setting where actors from different practitioners work together on a design task, through sufficient and structured exchange of each other knowledge related to design process and design content, in order to integrate and explore their knowledge and to achieve the larger common objective: the new product to be designed
Collaborative Team	A multidisciplinary team of practitioners with different educational background and different professions (Architects, Contractors)
Asynchronous Communication	Asynchronous communication is communication between senders and receivers which takes place at different times and at different places (Robbins 2001).
Synchronous Communication	Synchronous communication can be defined as the communication between senders and receivers at the same time, whether or not it is in the same place (Robbins 2001)
A Design	A model of an entity to be realized, as an instruction for the next step in the creation process. That entity can be an object or a process. A model is an abstraction of reality, usually it is an abstraction of an already existing reality, but in case of a design it is a model of a possible future reality (van Aken 2005). A completed design should only specify what the makers of the artifact need to realize that artifact (van Aken 2005).
Design Model	A model serves to record the different activities, by the use of one or more different methods, within a certain process. A model can be descriptive or prescriptive. The design-model used in this thesis is prescriptive in nature.
Design Support Tool	An instrument, a set of rules or a method that is used to support and stimulate progress of the design.
Interaction	The communication of speech, writing and sketching between different practitioners sharing knowledge about specific, task related, items. Communication has different ways it can be applied or represented by using types of representation (Brereton 1998, Sproul & Kiesler 1991-1998, Dainty et al. 2006, Forsyth 2006).
Integral Design	a design were all disciplines necessary and important are treated as part of, or contained within, the whole building design approach from the early stages of a project (Zeiler et al. 2009, page 211). With the focus in this research project, this definition is complemented with the following definition of an Integral Design: a design that can fulfill the requirements from the built environment and inhabits realization-knowledge. This prevents design failures.
Function-types	Relevant items that must be incorporated in the product for the design task, or essential items that the design has to fulfill. -Types of functions are related to type of knowledge of the practitioners, which is necessary to use, develop or research the type of function. Related to Architects this is object-related knowledge for object-related function-types. For roofers / installers this is

	realization-related knowledge for realization-related function-types. -Type of knowledge is again related to type of competence of the different practitioners. Competence profiles capture the expected type of knowledge related to a specific type of professional.
Knowledge sharing	Knowledge about a design is usually stored as tacit knowledge in the participating designer's heads, and converted to explicit formal knowledge, represented in design documents like: Sketches, images, drawings, text and estimations (Nonaka and Takeutchi 1995; Egbu et al. 2005). Thus, knowledge sharing in this research project means the notation of knowledge in an explicit way using the document option as described. Important for such knowledge sharing is an open mind and a learning attitude from the practitioners to understand each other's knowledge and learn how to speak the same language (Argyris, et al. 1985-2000).
Morphological Overview	A Design Support Tool, with the lay-out of a matrix (Zwicky and Wilson 1967) which is used to inhabit all those essential aspects that must, according to the design team, be incorporated in the product, or necessary functions (function-types) that the design has to fulfill. On the horizontal axis possible solutions (sub-solutions) to these functions (function-types).
Multidisciplinary Team	Teams which are necessary to fulfill the design-task, where two or more practitioners with different professions and knowledge background (e.g. structural engineer, Architect, Roofer, Installer) are working together.
Object knowledge / design knowledge	Knowledge on the characteristics and properties of artifacts and their materials (van Aken 2005, page 388). Design knowledge is for this research project the equivalent of object knowledge
Realization knowledge	Knowledge on the various physical processes to be used to realize designed artifacts (van Aken 2005, page 388). Knowledge about how to execute / built / construct the sub-solution(s) within a specific design task
Process knowledge	Knowledge relating to the characteristics and properties of design processes, which can be used to produce process-designs and realize an artifact (van Aken 2005, page 388)
Representation	All selected messages; written or spoken words, pictures, music or any other format (Shannon & Weaver 1949). All types and forms of concepts, terms, notations and language (Brereton 1998, Goldschmidt & Porter 2004)

Figure 5 Vocabulary of Terms and Working definitions.

3 RESEARCH OUTCOMES

In this Chapter of the research project results per DRM stage are described and explained. The research outcomes consist of answers formulated to the Research Questions and the Results to the Goals of the research project by the use of research improvements.

3.1 RESEARCH CLARIFICATION

Within DRM stage Research Clarification there are three main Goals. First; the problem identification by answering the related Research Questions. Second: the development of appropriate Research Questions for the Descriptive Study 1. Third: to formulate Hypotheses and related Measurable Success Criteria. Because this research project is related to the BS research group, before presenting the outcomes in 3.1.3 of the Research Clarification, the starting points of the BS research group are presented in 3.1.1. In the next sections the subsequent development towards the two first Goals are presented in 3.1.2. The Hypotheses and Measurable Success Criteria are formulated on the bases of the outcomes of the two first Goals and are presented as outcome 3 in 3.1.3. In paragraph 3.1.4 the overview of the finalized stage is presented in the overview DRM stages.

3.1.1 STARTING POINTS OF THE BS RESEARCH GROUP

In the current section a brief review is given of the starting points of the BS research group. This review aims to offer a clear picture of the underlying motivations for the research that the BS research group has worked on over the last decade. Some of these starting points are returned to in section 3.2.3, key-components of the Technological Design, in which it is shown how the current research project complements other work conducted by the BS research group.

To better understand the starting points of the BS research group, a short historical review of the design research field is in order. Most reviews consider the first wave of design research to have taken place between the mid-1940s and the late 1960s. Most of the approaches developed during this period are prescriptive in nature and are based on rational, systematic and methodical thinking. These approaches have these characteristics because ‘science’ was seen as the key to unlocking the secrets of design. The thinking behind such approaches is captured by Herbert Simon in his influential book entitled “The Science of the Artificial”, in which he argues that “the proper study of mankind is the science of design” (1973). For Simon, design was best approached from a rational, problem-solving perspective.

In the early 1970’s, shortly after Simon’s declaration, an exemplary prescriptive design model known as Methodical Design was developed for use on Mechanical Engineering degrees at the University of Twente, in the Netherlands (van den Kroonenberg 1974). Methodical Design was considered an important evolution in the development of prescriptive design approaches. This because it managed to combine some of the best ideas and practices from key thinkers in the German design schools (Matousek 1962, Hansen 1968; Roth et al 1972; Hubka 1980; Pahl and Beitz 1984) and in the Anglo-American designs schools (Hall 1962; Asimov 1964; Archer 1965; Grergory 1966; Krick 1969; Jones 1970, 1977). This combination of ideas resulted in an approach that structured the design process by decomposing it into different levels of abstraction. By doing so, the designer was guided into not only thinking about solutions on the component level, but also on the level of the whole design. The value of Methodical Design can be understood by turning to the words of one today’s leading design researchers. For Blessing, a distinguishing feature of Methodical Design is that “it is one of the few models that explicitly distinguishes between stages and activities, and the only model that emphasizes the recurrent execution of the process on every level of complexity” (Blessing 1993, pp.1398).

Zeiler (1993, 2007) was among the first group of proponents of Methodical Design. Much of Zeiler's research has focused on extending the prescriptive, Methodical Design approach in order to develop a new approach, Integral Design, that can be used by multidisciplinary design teams that include members from fields outside of mechanical engineering. To this end the BS research group have sought to look for useful and applicable insights in the more recently developed descriptive approaches to design. In this sense, the BS research group agree with Cross & Roozenburg, who argue that there appears to be good reasons for combining the prescriptive and the descriptive. This was argued because a generalized model of the design process would integrate the strengths of both approaches, while (hopefully) avoiding their weaknesses (1992).

By the 1980's the field of design research began to see the emergence of descriptive design approaches, which focus on the typical sequences of activities that take place within the design process. A good review of such approaches can be found in Cross (1996, 2001). Arguably the most popular of these descriptive design approaches is the approach developed by Donald Schön and explained in his book entitled The Reflective Practitioner (1983). In contrast to earlier prescriptive approaches, Schön believed that the practitioners of design were complex beings who should not be bound by the conventions of any particular design paradigm. Schön considered the designer to be a reasonable and sensitive agent who could reflect on the conditions that pertain to a given design problem and evolve strategies and methods to find adequate solutions on a responsive basis. This reflective process was argued also to take place after a design was completed. This approach allows a designer an opportunity to consider how a similar problem may be approached more successfully in the future.

The BS research group began researching the design process because of the following reasons. Their experience in Architectural and Engineering practice had clearly demonstrated that due to the growing complexity of design tasks in the built environment, traditional approaches to design were no longer suitable (van Aken 2005). The growing complexity of design for the built environment comes from the need to produce buildings that are more sustainable while at the same time more healthy and comfortable for the end users.

The first relevant full-scale research from the BS research group was applied within the situation of the Dutch Building Industry, on the subject of Integral Design for design-teams with equal educational background (Quanjel & Zeiler 2003, 2009). This research was the BS research group's first attempt at bringing Architects and Engineers together in multidisciplinary design teams to work on a conceptual design task in an integral way. In essence, this was an explorative project that layed the ground for future BS research.

Ultimately, this investigative project led to two key findings. First, despite the multidisciplinary design team lay-out, the conceptual design process was still dominated by the Architect. This was perhaps not overly surprising since in the status quo the responsibility for producing the conceptual design is generally placed mainly in the Architect's hands. In effect, what was observed in the research was that Architect's tended to lead the process and the engineers effectively acted as a support network to the Architect. To generalize, if, how and when Engineering knowledge was included in the design was largely determined by the Architect.

The second main finding confirmed a starting assumption of the BS research group. This assumption was that due to the complexity of modern design tasks; more knowledge is required from practitioners other than Architecture early in the design process. The end conclusion of this work was that more attention needed to be paid to the knowledge and skills of the different practitioners. In particular, three areas were identified that needed to be worked on. First, practitioners need to be more respectful towards other professionals' backgrounds, and positions. Second, practitioners need to gain greater acquaintance of each other's knowledge. Third, practitioners need to use a language and representation that can be shared by the other discipline(s). To achieve these improvements an open

mind and a learning attitude of the concerned practitioners is a pre-condition. Based on these findings it was concluded that all of the practitioners involved needed to engage in continuous training in both education and practice in order to learn how to become competent and productive members of a multidisciplinary design team (Quanjel & Zeiler 2003, 2009).

On the basis of these research findings, the BS research group set out to develop further projects. These projects aimed at improving the structuring and organization of multidisciplinary design teams and the constituent knowledge they possess in order to improve the design outcomes that they produce (Savanović 2009). While both the current research project and that of Savanović focused on multidisciplinary design teams, there are important distinctions between the two projects that need to be underlined.

The first difference to note is that Savanović's work sought to extend the Integral Design Model developed by Zeiler (1993, 2007). The current research project is set up to complement rather than extend Zeiler's Integral Design Model. While some of the key aspects of the Integral Design are retained in the current research project, the focus is not on design reasoning in Integral Design teams with a view to accounting for innovation. Instead, the focus is on the interaction and knowledge exchange of multidisciplinary knowledge within Collaborative Design teams. This in order to generate sub-solutions with a view to producing Integral Designs, that is, designs that not only fulfill the design task, but inhabits realization-knowledge as well as object-knowledge.

A further difference that results from the above is that Savanović focuses on "Integral Design Teams", while this research project focuses on "Collaborative Design Teams". The major distinction to be drawn here is that Integral Design Teams are expected to contribute equally from the beginning of the design process.

The practitioners observed in this research project, however, have very different levels of educational background, different kind of knowledge and different kind of design experience. Here, the focus is on identifying the types of knowledge each discipline could reasonably be expected to possess, and determining whether the different types of knowledge were exchanged and exploited during the design process.

3.1.2 RESULTS OF THE GOALS FOR RESEARCH CLARIFICATION

GOAL 1: PROBLEM IDENTIFICATION

In this research project the problem is twofold: First, a general lack of collaboration by practitioners in the design process is identified. Second, when collaboration does take place, it is often managed poorly, which results in non-Integral Designs, in this case roof designs. Such bad results consequently lead to unacceptably high energy use and wastage and also significant failure costs.

As mentioned in section 2.1, much of the background work and motivation for this research project came from the practical experience of the BS group members with senior working experience in Architecture and Engineering. It is also explained that for this reason, the Research Clarification can be classified as review.

The starting points of the BS research group were formulated as follows:

1: In order to provide Integral Designs for complex design problems, multi-disciplinary teams are required to work in a collaborative way.

2: Integral Design teams will need significant support in order to collaborate effectively and thus produce Integral Designs.

The BS research group had been working several years on this problem; therefore a review of the previous research conducted by the group was executed (Zeiler 1993, 2007; Quanjel & Zeiler 2003,

2009; Savanović & Zeiler 2007; Zeiler et al.2009). This review proved useful for two reasons. First, it highlighted previous approaches aimed at structuring multi-disciplinary design-teams through the workshop-setting. Second, the review of previous BS research provided a focus on more specific reviews related to the context of Collaborative Teams. Two factors to focus on became clear through this review. First, factors related to multidisciplinary teams to set in specific scenes for Integral Designs for roofs, or in other words the composition of Collaborative Design teams. Second, factors influencing the observation of such teams and its members in specific settings during the research process. Within a Collaborative Design Workshop the most compact team structure should consist of practitioners having object- and realization-knowledge. To observe the interaction and knowledge exchange in contribution of each member in the clearest way, two practitioners should be used that each has a different type of knowledge. For that reason an Architect and a Contractor are chosen. The Architect is used as representative who has the necessary object-knowledge where the Contractor: a roofer or installer represents a practitioner who has the necessary realization-knowledge. As explained in the Problem Definition section (page 30) Contractors working on roof-designs in Collaborative Design Teams are rare. This implies that the number of practitioners of Contractors which are available for this Collaborative Design Workshop is rather small. Therefore the current research project cannot use extended representative samples of the different practitioners in matched teams. For the Contractors this implies that roofers and installers are both representatives of the group of practitioners with realization-knowledge, without making a distinction. The BS research group reviews centered on various aspects of knowledge and its exchange and management, and sought to provide answers to the following two Research Questions:

RQ1 *What type of knowledge should the competent Architect, roofer and installer possess?*

RQ2 *When and how should this knowledge ideally be exchanged within a Collaborative Design Team?*

The end result of this stage is to derive Hypotheses that can be confirmed or denied in the final stage of the research project. In order to aid in this endeavor, success criteria also need to be provided. These outcomes of the research project are included in Chapter 3.

The Goal for this DRM Stage, Research Clarification, is to identify the problem. This Goal is derived from the result of a literature study and the answers to the related two Research Questions. To answer these first two Research Questions, a literature study is conducted. Each question is answered in turn below.

RQ1 *What type of knowledge should the competent Architect, roofer and installer possess?*

Clearly, the Architect and Contractor (roofer and installer) all have very different professional experience, skills and attitudes, which have led to the need to distinguish between different types of knowledge within the design process. As explained in Chapter 1 (page 27) an excellent typology of knowledge within the design process is provided by (van Aken, 2005), who distinguishes between:

Object Knowledge: knowledge relating to the characteristics and properties of artifacts and their materials;

Realization Knowledge: knowledge relating to the various physical processes to be used to realize designed artifacts;

Process Knowledge: knowledge relating to the characteristics and properties of design processes, which can be used to produce process-designs and realize an artifact.

The relevance of this typology to the present work is that the first two of the three categories neatly capture the predominant type of knowledge expected to be found in competent Architects and

Contractors, respectively. Since Architects are expected to have intimate knowledge of a wide range of artifacts this is the main reason why the category of object knowledge is a good description of the Architect's core knowledge type. However, those Architects who have had sufficient experience in the execution of the design during the construction phase should also have some realization-knowledge. In contrast, it cannot be expected that the average Contractor will possess a large amount of object knowledge. Alternatively, since it is has traditionally been the job of these practitioners to provide the means with which to build the Architect's design, Contractors are expected to possess extensive realization knowledge. The extent to which any of these practitioners possesses process knowledge will depend on the amount of experience they have in the various manufacturing processes that can be used to produce the components of the design. It was not the Goal in the current research project to investigate to what extent the designs could be actually built. As such, the main focus of the work was to create the necessary conditions to introduce and subsequently monitor the exchange of object and realization knowledge within a Collaborative Design Workshop. A key challenge in the current research project and in design research in general, is to find mechanisms that allow the design team to get their design thinking "on-line". The type of this challenge can be better understood when considering, as Nonaka (1999) points out, that knowledge can be further differentiated into the following categories:

Explicit Knowledge: easy to communicate while 'manifest' and captured / codified through representation (Brereton 1998; Goldschmidt & Porter 2004) into language, formulas, procedures and manuals.

Implicit Knowledge: personalized knowledge which is stored in the heads of the human being and hard to communicate (Nonaka 1999, pp. 10).

The result of this research project should be a Technological Design that is able to stimulate interaction and knowledge exchange between the practitioners in an explicit way. Knowledge exchange can be divided based on several aspects. First, the insight into the different types of knowledge needed from the various practitioners to fulfill the design task. Secondly, related to the other teams involved in the building project, to achieve the needed knowledge.

Although practitioners tend to use implicit knowledge often, the knowledge they communicate - explicit knowledge - is necessary and important for a first step to useful and effective collaboration in design. Effective and useful collaboration using explicit knowledge is assumed to be the basis for 'shared understanding'. Achieving shared understanding between actors from different practitioners might often be difficult, because these actors have different backgrounds, interests and perspectives on the design (Bond and Ricci 1992; Dougherty 1992).

It is assumed that in a Collaborative Design Workshop, practitioners who have different educational backgrounds and knowledge, Architects and Contractors, will learn new skills and competences for an effective and useful collaboration, and therefore be able to share and combine their respective knowledge in order to develop a 'new design' in response to the design task. For that reason the practitioners need; 'to be able to integrate and explore their knowledge and to achieve a larger common objective: the new product to be designed' (Kleinsmann 2006).

In short the following answer to the RQ1 is formulated:

A RQ1 As confirmed by the literature review and within the context of the collaborative setting for roof design the Architect represents 'object knowledge' for designing, and the Contractor (roofer / installer 'realization knowledge' for the execution of the design. The Architect, having a specific background, tends towards 'reflective practice' (Schön 1983) in developing the design-problem, which is in an iterative process. The Contractor in contrast, tends towards 'rational problem solving' as Simon (1973) explains, which is a linear and reactive process is

in fact. The explicitly used knowledge by the different practitioners is necessary for an effective use and sharing of knowledge during the design-process.

The next Research Question to be answered is:

RQ2 *When and how should this knowledge ideally be exchanged within a Collaborative Design Team?*

The first point to note is that in practice the Architectural design process is complex and often has a vague structure that can easily change from task to task. However, it is possible to provide a generalised picture of the stages that the design process goes through. The designer starts from an ill-defined problem and through different steps and stages progresses towards a blueprint for a solution (Simon 1973).

The conceptual design stage in the status quo is a particularly important stage in the design process as it is here that many important decisions are made even though not all relevant information, knowledge and practitioners are available then (Wichers Hoeth & Fleuren 2001; Chiu, 2002; Zeiler et.al. 2007). This influence and information contradiction is called the design process paradox (den Hartog 2003; Ullman 1992), as shown below in Figure 6:

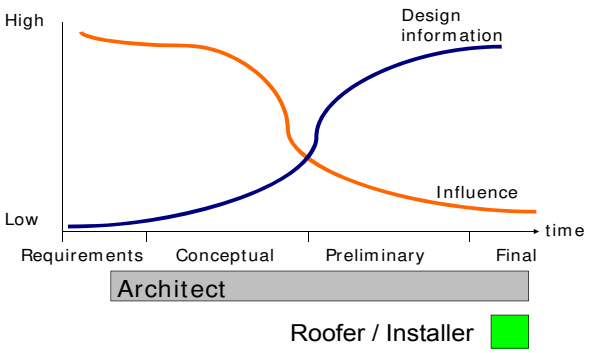


Figure 6 Traditional setting: relationship available design-information (blue curve) and the influence of design-decisions.

Figure 6 shows on the x-axis the time-line of the design-process and the main practitioners who are involved related to the current research project; here, the roofer / installer (Contractor) is customarily involved only in the final stage of the design (green line-box) and the Architect throughout the end of the requirement-stage up to the final design-stage (grey line-box).

In the current research project, the aim is to support all practitioners with information about the tasks and decisions of the other practitioners. Supplying this information will improve understanding of the combined efforts (den Hartog 2003). Related to an Integral Design for roofs, then, it is necessary to have not only design knowledge available but also specific realization knowledge for roofs, in an early stage of the design process. By facilitating the introduction of this knowledge, the conceptual design stage in the present research project can be illustrated as follows in Figure 7. This figure shows the situation where the roofer / installer (Contractor) is involved in the conceptual design-phase and can contribute design-information through realization-knowledge. In the dotted frame: the focus of the current research project.

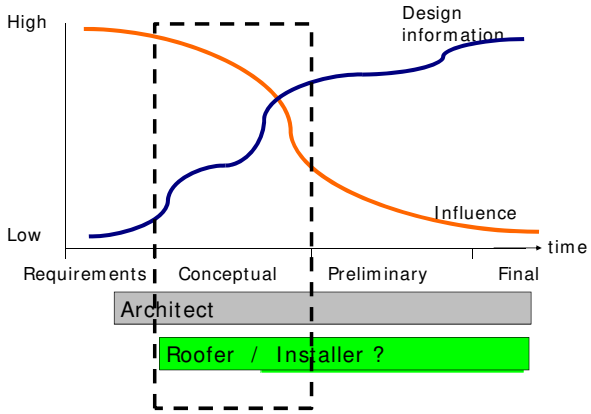


Figure 7 Collaborative Design Workshop: more available design information (blue curve) in the conceptual phase and design influence by involved participants.

So concerning the *When* question the following answer to RQ2 is formulated:

A RQ2 *When*

> Process knowledge can be exchanged most successfully in the preliminary stages where actors need to make creative decisions about the design in order to reduce uncertainty and narrow the solution space; this process requires collaboration in these early phases

Of interest in the current research project is how best to include and integrate the knowledge of all relevant practitioners in the preliminary stages in order to provide a more considered delineation of the solution space. In addition, the research project also wishes to provide a means to structure and organize the contributed knowledge of the team in order to create the basis for an Integral Design.

While the answer to *when* the different types of knowledge (object, process, realization) should be included is now understood, no answer has yet been given as to *how* this knowledge should be introduced. The previous research of the BS research group was used to guide this answer. At the time when the current research project began, the BS research group had already carried out research into the organization of design teams and had conducted various tests involving design teams made up of professional practitioners in a series of workshop format settings, the results of which are described in Quanjel & Zeiler (2003, 2009). The main finding of interest for the current study was that both the professional practitioners and the Professional Organizations that supplied the practitioners strongly agreed that the workshop setting provided a suitable environment for knowledge exchange to take place. The practitioners could literally be seen to be improving their ability to collaborate via the learning-by-doing (Schön 1987) environment provided by the workshop format.

Thus, the second part of RQ2, that is, *how the knowledge should be exchanged,* can now be answered:

A RQ2 *How*

> Knowledge exchange between the practitioners of the Collaborative Design teams being studied should be done via a face-to-face setting to avoid 'noise' and to stimulate collaboration and interaction.

GOAL 2: DEVELOPMENT OF RESEARCH QUESTIONS FOR DESCRIPTIVE STUDY 1

It is important to point out here that in practice roof designs are not commonly produced by Collaborative Design Teams despite the recent development of new functions and possible solutions as part of the total design-solution on the roof. The requirements for such roof designs are now strongly related to sustainable energy production and sustainability in a broader sense (double use, water management, and bio-diversity). However, there is a growing realization that new ways of organizing the design and realization of these functions and possible solutions may be wise. The review conducted demonstrated that facilitating the exchange of knowledge between practitioners operating in Collaborative Design Teams is necessary to deal with the complexity of design. Ultimately, though, the lack of current application of such approaches means that it was not possible to provide a detailed picture of reality. What was possible, however, was to provide an initial overview of what kind of knowledge is used and which constraints are found in design for projects in practice where roofs play an important role. Because the type of questions raised are so-called *what* and *how* questions, the method used to provide this initial overview was a review of Case Studies (Yin 2003) of designs for energy efficient roofs.

Based on this the main question that guides the Case study project scan be formulated as:

RQ3 *What factors hindered the success of the Case Study projects?*

The main Goal of this research project is to develop and test a Technological Design: an effective type of Collaborative Design Workshop with a Practice Setting to observe and stimulate interaction and knowledge exchange, between an Architect and a Contractor. They need to work as a Collaborative Design Team on a complex Design Task of a design for a roof supported by the application of a Design Support Tool. It is assumed that such a model stimulates interaction and knowledge exchange by its users. In order to conduct this development and testing in a transparent and robust way, the components of such a Technological Design need to be decided in advance and accounted for throughout the research project. The Research Question that needs to be answered then is as follows:

RQ4 *What are the necessary key-components of the Technological Design?*

3.1.3 OUTCOMES FOR GOALS OF RESEARCH CLARIFICATION

OUTCOME 1: ANSWERS TO RQ1 AND RQ2

The identification of the problem in this DRM stage could be determined from the previous studies in the BS research group and literature reviews. The outcomes are formulated Research Questions RQ1 and RQ2 with the answers to these Research Questions:

RQ1 *What type of knowledge should the competent Architect, roofer and installer possess?*

A RQ1 As confirmed by the literature review and within the context of the collaborative setting for roof design the Architect represents ‘object knowledge’ for designing, and the Contractor (roofer / installer ‘realization knowledge’ for the execution of the design. The Architect, having a specific background, tends towards ‘reflective practice’ (Schön 1983) in developing the design-problem, which is in an iterative process. The Contractor in contrast, tends towards ‘rational problem solving’ as Simon (1973) explains, which is a linear and reactive process is in fact. The explicitly used knowledge by the different practitioners is necessary for an effective use and sharing of knowledge during the design-process.

RQ2 *When and how should this knowledge ideally be exchanged within a Collaborative Design Team?*

A RQ2 *When*

Process knowledge can be exchanged most successfully in the preliminary stages where actors need to make creative decisions about the design in order to reduce uncertainty and narrow the solution space; this process requires collaboration in these early phases

A RQ2 *How*

Knowledge exchange between the practitioners of the Collaborative Design teams being studied should be done via a face-to-face setting to avoid 'noise' and to stimulate collaboration and interaction.

OUTCOME 2: HYPOTHESES AND MEASURABLE SUCCESS CRITERIA

From the main Goal of this research project and by answering the two Research Questions of the Research Clarification the following Hypotheses and related Measurable Success Criteria can be formulated.

Hypothesis 1. *The Collaborative Design Workshop leads to interaction and knowledge exchange between the practitioners involved.*

Measurable Success Criteria 1 (MSC1): percentage of different communication activities (speech, sketch, MO) and object- and realization-knowledge notated as function-types and sub-solutions by the different practitioners.

Hypothesis 2. *The Collaborative Design Workshop stimulates interaction and knowledge exchange for Integral Roof Designs by incorporating realization knowledge*

Measurable Success Criteria 2 (MSC2): the inclusion of a number of realization-related function-types and sub-solutions by the practitioners.

By answering the two Research Questions (RQ1, RQ2) and formulating the Hypothesis the problem identification is concluded.

By answering the two Research Questions (RQ1, RQ2) and formulating the Hypotheses the problem identification is concluded, however to proceed the research project according the DRM framework, the next Research Questions need to be formulated. These were formulated above and are summarized in outcome 3:

OUTCOME 3: RESEARCH QUESTIONS RQ3 AND RQ4

The following two related Research Questions for the Descriptive Study 2 could be formulated:

RQ3 *What factors hindered the success of the Case Study projects?*

RQ4 *What are the key-components of the Technological Design ?*

3.1.4 OVERVIEW DRM STAGES, THE CORRESPONDING RESEARCH QUESTIONS AND GOALS

The first Goal for this DRM stage, the Research Clarification, was to identify the problem. Based on literature study and experience from the BS research group the results are three folded. First; there is a need for explicitly used object-knowledge of the Architect and realization-knowledge of the Contractor in a collaborative setting to apply the reflective practice and rational problem solving. Second: the most successful period of time in the design process to exchange process- and object-knowledge combined with the needed realization-knowledge is in the early design phase. Third: the

face-to-face setting in a workshop-format is the most optimum as a collaborative setting. The second Goal, formulating Hypotheses and related Measurable Success Criteria could also be defined. In the overview of the DRM stages in Figure 8 the completed DRM stage, Research Clarification, therefore is marked in yellow.

With these outcomes about the problem identification from the Research Clarification this problem has to be confirmed in actual practice and key-components which influence this problem have to be determined. This is executed in the Descriptive Study 1 by applying Case Studies, additionally use of the experience of the BS research group and literature study. The DRM-scheme of Figure 8 presents the Descriptive Study 1 as part of the total DRM research and is marked in yellow. This overview is used to show that this part of the research project is finished now; Research Questions are answered and the formulated Goals are reached. In this DRM stage no research improvements are set.

	DRM Stage	Research Question(s)		Goals
1	**Research Clarification**	**RQ1**	*What type of knowledge should the competent architect, roofer and installer possess?*	Problem identification +answers RQ1-RQ2
		RQ2	*When and how should this knowledge ideally be exchanged within a Collaborative Design Team?*	Development of RQ3 and RQ4 Hypotheses and Measurable Success Criteria
2	**Descriptive Study 1**	**RQ3**	*What factors hindered the success of the case-study projects?*	Problem is expressed in practice Answers to RQ3+RQ4
		RQ4	*What are the necessary key-components of the technological design?*	Key-components identification Development of RQ -5-6-7-8-9
3	**Prescriptive Study**	**RQ5**	*Were the tasks sufficiently complex to require the collaboration between the practitioners?*	Pre-Answers to: RQ -5-6-7-8-9 Research Improvements
		RQ7	*Did the face-to-face setting provided by the workshop allows collaboration between the practitioners working on the design task?*	
		RQ6	*Did both types of practitioners succeed in contributing realizations knowledge?*	
		RQ8	*Did loose introduction of the Morphological Overview lead to acceptance of the tool by the practitioners?*	
		RQ9	*When used did the Morphological Overview stimulate for the exchange and structuring of knowledge between the practitioners?*	Development and application of the Collaborative Design Workshop lay-out Finalizing of Research improvements
4	**Descriptive Study 2**	**Test RQ 1-9**		Answers to: RQ5-6-7-8-9 Testing the Key-components and Research improvements in the Definitive Collaborative Design Workshop Verification of the Key-components and the analyzing tools Evaluation of the Hypotheses and Measurable Success Criteria

Figure 8 DRM-stages with corresponding Research Questions and Goals.

Figure 8 shows an overview of the DRM stages with the corresponding Research Questions and the Goals. The overview is used in the next Chapter to provide a summary and to show when research improvements are applied and its development during the research project finally leading the testing of the key-components and finalized research improvements in the Definitive Collaborative Design Workshop.

3.2 DESCRIPTIVE STUDY 1

There are three Goals formulated for this stage. The first Goal is to find out if the problem is expressed in practice and identify the underlying cause(s) of the problem via analyses of the Case Studies. This Goal is related to Research Question RQ3 as defined in section 3.1.3. Second, as formulated in research question 4 in section 3.1.3: The key-components of the Technological Design need to be identified. The third Goal is to develop the next Research Questions which are needed to identify the effects of the key-components concerning interaction and knowledge exchange a Collaborative Design Workshop.

3.2.1 RESULTS OF THE GOALS FOR DESCRIPTIVE STUDY 1

GOAL 1: PROBLEM EXPRESSED IN PRACTICE

As described before, one aspect of the identified problem is a lack of collaboration in practice, concerning roof designs. This meant that a comprehensive Descriptive Study in practice was not possible. In practice, a very limited number of Collaborative Design teams working on roofs could be identified. This limited number underscores the lack of collaborative approaches in the status quo. However, the case-studies chosen are reprehensive ones for analyzing in this research project.

The main criteria for the choice for the type of Case Studies were as follows. First, they should be state of the art related to the use of sustainable energy on roofs. Second, they should be comparable in type of cases. Third, the Case Studies should be representative of substantial applications of the realized sustainable energy projects in the Dutch Building Industry. As a result for these criteria, three different important major projects from practice as posted by the Government were chosen and studied. A wide range of literature relating to each Case Study was reviewed, including direct information from the team-leader involved from TNO and ECN. Besides the given criteria is also of interest that these Case Studies also represent some of the largest European projects researching sustainable energy use and application in residential housing.
The following projects were reviewed as Case Studies:

1. New Sloten, Amsterdam, 100 PV-houses, 1991-1996

2. Amersfoort Nieuwland, 1MW PV project, 500 houses, 1997-2000

3. HAL Location, ‘City of the Sun’, 5MWp, Heerhugowaard, Alkmaar, Langedijk, 2500 dwellings, 1987-2009

All chosen projects were supported in one way or another by the Dutch Government and represent some of the largest European projects researching sustainable energy use and application in residential housing. It is interesting to note that without the support of the Government, which was politically motivated to encourage and stimulate innovation in low energy buildings; it is likely that none of these projects would have been commissioned. Additionally can be stated that in project-based industries, as the Building Industry, the investments in research and development of innovation is sparse and difficult to organize (Taylor & Levitt 2004). These two aspects demonstrate the difficulties to organize Collaborative Design teams for Integral Designs for roofs.

Each Case Study is first briefly introduced. To aid the analysis of the Case Studies, of management- and specific evaluation-reports from the following project managers, agencies and organizations involved in the projects were used: Project bureau HAL 2002; Westerhuis et al. 2008; Gaiddon et al. 2009, and Wagenaar 2010. A full review overview of the Case Studies related to the different references is provided in Appendix 1 (page 2 – 4). The analysis leads to a discussion of the causes

and consequences of failures. A subsequent literature review was conducted in order to determine what key-factors could contribute to a solution for the problem identified in Chapter 1.5 (page 30).

CASE STUDY 1: NIEUW SLOTEN, AMSTERDAM, 100 PV-HOUSES, 1991-1996

The Nieuw Sloten PV houses project was the first example of a large-scale application exploiting the use of PV panels for housing. The project, which was led by the local electricity company, comprised of installing PV to all houses within a new housing development. The project described itself as 'an important demonstration of PV in urban areas' and it was hoped to 'pave the way' for future projects in similar areas.

The project was challenging in nature because there were a number of technical issues that had to be worked out for the first time. In addition, the project involved many Contractors with little or no previous knowledge or experience of working with PV (Figure 9).

Figure 9 Examples of projects of Nieuw Sloten, Amsterdam.

CASE STUDY 2: AMERSFOORT NIEUWLAND, 1MW PV PROJECT, 50 HOUSES, 1997-2000

This second project, which took place In the Nieuwland expansion area of the city of Amersfoort, was at that time the largest urban PV project under development. The project was organized and run by the municipality of Amersfoort in association with the local electricity utility company, REMU, and a coalition of real estate developers. The project aimed to create a sustainable development with schools, sports and leisure facilities and over 500 houses by pursuing solar optimization. This amounted to integrating PV modules into facades and roofs wherever possible. The total amount of PV installed was approximately 12,300 m2. A significant point of interest from this project is that all of the urban planners, Architects and developers involved in the project were required to cooperate closely during the implementation stages of the project (Figure 10).

Figure 10 Examples of projects of Amersfoort Nieuwland.

CASE STUDY 3: 'CITY OF THE SUN', 3.6 MWp, HEERHUGOWAARD, ,2500 HOUSES, 1987-2009

The final project took place in Heerhugowaard, part of the so-called HAL region of the Netherlands, Heerhugowaard, Alkmaar and Langedijk. The aim of this project was to install a total of 3.6MWp of PV on a total of 3500 homes in a new urban district (Figure 11).

This ambitious project was, at the time, among the largest urban-scale PV projects in the world. Inspired and supported by the Municipalities of Alkmaar, Heerhugowaard and Langedijk have led to the conception of City of the Sun, located slightly north of Amsterdam. A section of polder became an example of sustainability not only in the field of energy and use of materials, but also in the social, natural, cultural and economical fields. The City of the Sun is the largest CO2-neutral residential area in the world and generates 10 MW of energy from wind and solar power and uses natural water-filtration systems.

This project established the following results. First; the low to zero-emission new housing developments with PV, second; assessment of the PV-related risks and risk abatement strategies for project developers. Third; replication costs of building integrated grid-connected PV in housing projects and fourth; a flagship and landmark to future replication and follow up projects all through Europe with extensive exposure of the project.

Due to the size and ambition of the project, significant information about problems and success is available about the development stage.

Figure 11 Overview of the project 'City of the Sun', Heerhugowaard.

Rather than proceeding on an individual Case Study basis, the outcomes of all three Case Studies are presented together in an overview in order to better demonstrate and understand the main causes of failures and corresponding effects. By taking this approach, it was possible to identify two main causes of failures: *lack of competence* and *poor knowledge exchange and structuring*. Each item is discussed below alongside the corresponding effects.

LACK OF COMPETENCE

Since all of the projects aimed to provide municipal developments, urban designers were involved in the original conception of the design. However, a significant lack of knowledge of PV was identified in some of the urban designers, which meant that crucial aspects of the design such as orientation, structure and shading were dealt with, so to speak, in the dark.

All Case Study projects sought to work on the basis of scenes comparable to Collaborative Design teams from the conceptual design phase forward. However, due to the scale of the projects, such

teams require other types of practitioners which is out of the scope of this research project. Perhaps the most notable addition to a design team on such a large job is the project manager, who is responsible for organizing the various nodes of the team and the knowledge provided by individual team members. A common feature of the projects was that the individual team members were not provided with a sufficiently comprehensive and clear picture of the responsibilities and progress of other team members.

The next level after the project management level is the design process proper, led by the Architect. Usually at this level, the Architect is in interaction with other practitioners such as the structural Engineer and Building Physics Engineer working on the conceptual design. One of the main responsibilities of the Architect is to guide the design team in terms of the overall vision of the project. However, like the urban designers, some Architects had little or no knowledge of PV applications for building designs. A perhaps connected point is that some of the Architects involved in the projects considered PV to be a design limitation rather than an opportunity to push the envelope of design within a team setting. This meant that some of the design teams did not give enough priority on PV solutions within the design.

The final project level is the actual realization of the design. In the Case Studies, and in the current research, the realization aspects of interest are those relating to the roof. Due to the relative novelty of applying PV to buildings, many of the roofers and installers involved in the projects lacked the competence required to realize the designs without failures. While many of these Contractors had some experience of applying solar PV applications in fields, very few had direct experience of applying PV in bolt-on or built-in applications. However, it was quickly understood that there are significant differences between these situations. It could be said that there was a general lack of craftsmanship on behalf of the roofers and installers in terms of dealing with the application of relatively new technologies. However, additionally can be argued that there is also a lack of competence with the architect which has to lead the design-process related to knowledge of the realization of these concepts.

The lack of knowledge and competence of the Collaborative Design teams led to a lack of focus on key aspects of the design such as waterproofing, fringe-detailing, roof-fringing and roof-perforating. In the subsection 3 the consequences of these shortcomings are given. Before that, the following subsection highlights shortcomings in the knowledge exchange and management within the Collaborative Design teams working on the projects.

KNOWLEDGE EXCHANGE

The Case Studies chosen were investigated to explore the concerning interaction and knowledge exchange object- and realization-knowledge in design teams operating in practice. The extent to which the design teams in the Case Studies can be described as collaborative is arguable. The first signs of this come from the constitution of the teams themselves; not all of the design teams included all of the necessary professional practitioners required to represent the totality of knowledge needed to produce and realize an Integral Design. Perhaps the clearest example of this is the under representation of Contractors in these collaborative design teams, even though all of the projects are by definition large construction projects.

The low number of Contractors in design teams in practice can be explained by the fact that knowledge from these Contractors was sought too late in the process by other practitioners in the design teams and their clients. This meant that the knowledge of Contractors is mostly used in an ad-hoc manner to clarify or verify the ideas of the design team members. This tendency is shown by an example in one of the Case Studies. Here the design team was organizing a mock-up roof construction for the design without consulting the relevant professional for input on practical aspects of

the design. The result was that changes needed to be made to the mock-up design once the right knowledge had finally been contributed.

Another significant problem was that changes to the design were not always communicated to all parties within the Collaborative Design Team. Striking examples of this lack of knowledge sharing were identified in more project-situations. In one Case Study a major change to the construction of the roof was not fully communicated to all members of the team, and in another the reference height of the roof was changed, but some of the team members were not informed.

What can be seen from the problems identified above is that only a part of the needed knowledge from all of the required practitioners is sought early enough in the process. In addition, when changes are made to the design, this knowledge is not always disseminated in full to the entire team. In essence, there is a lack of a tool or system to manage these aspects within a Collaborative Design team. The lack of introducing and use of an appropriate tool or system can be related to the manager to manage these aspects. However, two remarks can be made to this presumption. First, not only managers have knowledge and skills to introduce these tools, other type of competent practitioners are also having these competences. Second, the setting of a Collaborative Design process cannot always be organized with a special manager, so the competences of the practitioners involved should inhabit the knowledge about such tools. The importance of avoiding the problems noted above can be better understood through a discussion of the consequences, which is provided below.

CONSEQUENCES

The issues with competence and knowledge exchange and management led to a number of practical problems within the projects. One rather costly consequence in one project was the estimated 1-5% loss of productivity in actual practice due to the incorrect coupling of differently oriented areas to the PV convertor. On another of the projects, considerable productivity loss of the system was identified because the ventilation underneath the PV applications did not reduce the temperature of the cells sufficiently. In a third example, man-bearing-prefab-plates had to be used as replacements for the originally installed man-bearing foil, which proved not to be robust enough to offer a waterproof finish. These examples are evidence that to create a Collaborative Design Team capable of producing Integral Designs it is not enough to simply select any given representative from each of the identified professions; it must also be ensured that the chosen representatives have sufficient knowledge and practical experience of the type of design task to be worked on.

Calculating the financial cost of such consequences was not possible since the project reports available did not offer comprehensive financial breakdowns. In fact, this is the norm for publicly available reports on the majority of large construction projects. However, it is not difficult to imagine that the cost of replacing an entire roof is significant. Not only do the new materials need to be paid for, but the old materials need to be disposed of at a cost. In addition, more man hours are required to carry out this work and it is likely that other aspects of the construction will be delayed, leading to yet further costs. Calculating the cost of a loss of productivity is a slightly easier matter; this can be done by multiplying the energy price by the produced units of electricity. However, it must be kept in mind that unit prices change constantly, and have undergone significant changes since the projects discussed above were completed. Nonetheless, on projects of such a large scale, even a loss of a few percent represents a significant financial setback over the life of the building.

Aside from the financial cost, there are obvious environmental and sustainability issues at stake here. Using the example above, the energy used to produce the materials for the failed roof can be seen as wasted energy. On top of this, extra energy and resources are needed to dispose of or recycle the old roof. Finally, yet more energy is required to produce the materials for the new roof. In order to minimize the occurrence of such undesirable consequences in future construction projects, particularly in pioneering projects like those in the Case Studies, it is argued here that better organization and

management of knowledge sharing and knowledge structuring within these Collaborative Design teams is essential. With these results the related Research Question RQ3 can be answered.

A RQ3 In summary, the three Case Studies suffered mainly from the same two primary causes. These main causes identified as a lack of competence, poor knowledge- exchange and structuring, which led to significant failures in all three projects. In order to seek workable remedies for these causes of failure, a further literature review was conducted.

GOAL 2: IDENTIFICATION OF THE KEY-COMPONENTS

The insight gained from the Case Studies was used as a basis to work towards the second Goal of this stage. In order to build upon these insights, the previous experience of the BS research group was used and further review of BS research was undertaken.

The main BS-research reviewed for this purpose was based on the work of Zeiler (1993, 2007). The previous work referred to began with the "Integraal Ontwerpen" workshops (Integral Design Workshops) for practitioners held between 2000 and 2003 in Delft. The approaches as well as the results of this study were discussed with an expert-group. This expert-group was selected from a wide range of different type of leading practitioners involved into Integral Design processes in practice as well as some of the major professionals from research and education with Integral Design as knowledge field. During the execution of the research, 150 practitioners attended the workshops freely through Professional Organizations (Quanjel & Zeiler 2003, 2009). From this analysis aspects which influence the Integraal Ontwerpen workshops and need to be managed during the research were identified for Design Teams with practitioners with equal educational background: Task, Team, Setting, and Tool(s). However for the current research project with a different research focus on Design Teams consisting of practitioners with different educational background, it was not evident the same aspects could be adopted. Therefore additional research was necessary to identify the key-components for the Collaborative Design Workshop.

Since the research deals with practitioners working in a collaborative setting on design tasks, some of the key-components of the Technological Design are logically predetermined. These key-components are Design Task and Collaborative Design Team. Without a Design Task, there is no job for an individual designer or a design team to work on, and thus no object of study for the design research. In terms of task, many design tasks facing the built environment today need to be understood as highly complex, or wicked problems. Both practice and research show that the more complex the problem, the more the need to exploit for a multidisciplinary team to work towards an adequate solution. This explains the need to include a Design Team as key-component in the Technological Design is redundantly obvious.

In addition to these two predetermined key-components, the research needed to introduce further elements to the Technological Design on the basis of the starting assumptions of the BS research group and on the results of the Case Studies, which showed that Collaborative Design teams cannot be expected to produce the desired design outcomes without substantial guidance and assistance. For reasons described below, the additional two key-components of Practice Setting and Design Support Tool were integrated with Design Task and CD Team to form the Technological Design. Each of the individual key-components of the Technological Design is discussed in more detail below. However, for the reader's convenience, a global answer to RQ4 is provided here:

> The key-components that are assumed to be most important in the Technological Design are: Design Task; Collaborative Design Team; Practice Setting; Design Support Tool.

To be able to answer Research Question 4 fully, eight sub-questions are formulated concerning the following aspects of the key-components: realistic/authentic tasks, to organize competent teams, to

develop a setting that stimulates knowledge exchange between the practitioners, while also providing a suitable setting for observation.

The sub-questions are:
1. What design tasks are relevant to contemporary practice and relate to the problem identified?
2. What level of competence should each discipline member of the team possess?
3. What is the minimum required level of expertise (as indicated in Figure 12, page 61) of the participating practitioners, Architects and Contractors, for the current research?
4. How can the level of expertise of Architects and Contractors be guaranteed?
5. What kind of setting would be appropriate for the practice of Collaborative Design and also for the analysis of the research?
6. What type of collaboration has the best focus compared to practice, and thus is the most appropriate for the Technological Design to be applied in practice in the near future?
7. What kind of setting for the Collaborative Design teams can be managed within the current PhD research project?
8. What type of Design Support Tool is capable of capturing and structuring the knowledge exchanged between the different practitioners participating in the workshops?

These sub-questions are answered in the next paragraphs, related to the assumed key-components.

KEY-COMPONENT C1: DESIGN TASK

The 1st sub-question to be answered in this section reads:

1. What design tasks are relevant to contemporary practice and relate to the problem identified?

As stated in the introduction, the present and future built environment demands for designs that are not only satisfactory in terms of avoiding failures and associated failure costs, but designs that integrate new technologies in order to arrive at energy efficient solutions. In this research project the area of design of interest is roofing designs as part of a total building design; an Integral Design.

To make the workshops relevant and rewarding for the professional practitioners and the organizations that supplied them, tasks needed to be designed that could in theory be applied in the present market. In order to allow the involved practitioners to apply the approach in their daily practice, it is of course necessary to provide both a setting and a range of tasks that clearly demonstrate the benefits of multidisciplinary collaboration. Put simply, the tasks needed to be designed in such a way that they could be realistically applied in the current built environment.

There are two other main items related to this sub-question. First; the requirements related to the functions of the result of the design task, and second; the requirements to research the appropriate design tasks. To discuss the first requirement, the functions of the result of the design task it is important to point out the relationship between functions and function-types. A function can be defined as ‘what is performed by an artefact’ (Rosenman and Gero 1998, page 336), where for an artifact like a building more and different types of functions can be described. As explained in Chapter 1.4, function-types are relevant items that must be incorporated in the product for the design task, or essential items that the design has to fulfill. Function-types represent items of object- and realization-knowledge. This implies that the design task should inhabit not only function-types specific for a roof but simultaneously function-types related to the total building design, the Integral Design.

Second, in terms of the research requirements, the range of tasks that were used needed to be comparable in order to allow analysis to be carried out and conclusions to be subsequently drawn. The findings of one individual workshop alone would not be sufficient to draw any meaningful conclusion from. Gaining confidence in the approach, the use of key-component and research

improvements in this research project could only be achieved by arriving at the same or very similar findings over a sufficient number of workshops as semi-experiments.

Although the answer to the sub-question in this section may seem rather obvious to the reader, the tasks in the current research project required the multidisciplinary team to produce designs for roofs that do not suffer from the failures noted in the introduction, while at the same time are conscious of the need to provide energy efficient solutions; Integral Designs for roofs.

In addition to providing relevant tasks, the current research also needed to provide research improvements and tools that could facilitate both the realization of the tasks on the one hand and the analysis of the tasks on the other hand.

KEY-COMPONENT C2: COLLABORATIVE DESIGN TEAM

The first assumption made in this research project was that organizing a Collaborative Design Team for roofs is an essential first step towards solving the identified problem. As explained in the Problem Definition and related to RQ1 (page 44) such a team should consist of an Architect and a roofer / installer. The second sub-question reads:

2. What level of competence should each discipline member of the team possess?

Since the problem focuses to Integral Designs for roofs, the first discipline that needs to be identified concerns the practitioner who is responsible for creating a roof design. In the status quo, it is important to keep in mind; that in Dutch design teams the Architect is largely responsible for the totality of the design, of which the roof is seen as one constituent component, and that the Structural Engineer, Building Physics Engineer, HVAC Engineer and Project Manager have their complementary roles,. Thus, due to this dominant position, the Architect was the first choice for the design team. In addition, the discipline responsible for providing practitioners to manage the realization of the roof design needed to be identified. Again, this was a rather straightforward matter: the professional in question here is the Roofer. However, as well as these two identified practitioners, due to the increasing trend of adding (energy) parts to the roof design, it was wise to identify which discipline was responsible for integrating these technical parts into the roof. For that reason, the Installer was chosen as suitable practitioner equally matching with the Roofer.

Identifying the required practitioners was a necessary first step, but cannot be considered as sufficient to remedy the problem at hand. As the figures reported earlier demonstrate, there are clearly very serious failures occurring on a regular basis as a result of non Integral Designs for roofs. To be sure that this is not simply the result of incompetent practitioners, for the purposes of this research the competence of the practitioners involved needed to be understood and controlled for. In terms of the present research then, the following sub-questions emerge:

3. What is the minimum required level of expertise (as indicated in Figure 12, page 61) of the participating practitioners, Architects and Contractors, for the current research?

4. How can the level of expertise of Architects and Contractors be guaranteed?

In order to answer the third sub-question, Dorst and Reymen's work on levels of expertise provide insights that are suitable and adequate (Dorst & Reymen 2004). This literature is inspirited on the skill-based model of Dreyfus (2003) although his work is not published officially. Dreyfus distinguishes the varying levels of competence of practitioners and defines them within a scale. These different levels of competence are presented in the overview in Figure 12 (page 59) and included and described in detail in the definitions section of this thesis.

To answer sub-question 3 first the list with levels of expertise needs to be understood (see the left column in Figure 12) to identify reasonable minimum requirements for the competences of the

Architect and Contractor. This list of expertise is developed on the basis of the references for the list-of expertise (Dorst and Reymen 2004; Dreyfus 2003) and additional literature on experience with expertise (Shen and Liu 2003, Ericsson and Smith 1991).

Line 1 of the table, Novice, represents new entrants to a professional field with limited knowledge and little or no real experience in the field. This limited knowledge and experience rendered novices in appropriate subject for the current research. Not only would knowledge transfer within the Collaborative Design teams used in this research suffer greatly due to novices not being able to provide sufficient knowledge, the lack of practical experience of novices would hinder their ability to draw on analogous solutions. In addition, novices are logically lacking experience and skill in working in multidisciplinary teams, which again would hinder the progress of the current research.

For the purposes of the present research, the advanced beginner, in line 2 of the table, suffers to a large degree from the same limitations as the novice. Although some knowledge and experience has been gained, the limited breadth and depth of it is not sufficient to allow a high degree of analogous thinking, or a high degree of autonomous thinking. The advance beginner is capable of little more than following maxims or principles of some sort. Thus, the advance beginner also falls below the minimum required level of expertise for the current research.

Level Of Expertise	**Knowledge and Characteristics**
1. Novice:	A novice will consider the objective features of a situation, as they are given by the experts, and will follow strict rules to deal with the problem
2. Advanced beginner	For an advanced beginner the situational aspects are important, there is a sensitivity to exceptions to the 'hard' rules of the novice. Maxims are used for guidance through the problem situation
3.Competent:	A competent problem solver works in a radically different way. He selects the elements in a situation that are relevant, and chooses a plan to achieve the Goals. This selection and choice can only be made on the basis of a much higher involvement in the design situation than displayed by a novice or an advanced beginner. Problem solving at this level involves the seeking opportunities, and of building up expectations. There is an emotional attachment, a feeling of responsibility accompanied by a sense of hope, risk, threat, etc. At this level of involvement the problem solving process takes on a trial-and-error character, and there is a clear need for learning and reflection, that was absent in the novice and the beginner (Dreyfus 2003).
4.Proficient:	A problem solver that then moves on to be proficient immediately sees the most important issues and appropriate plan, and then reasons out what to do
5.Expert:	The real expert responds to specific situation intuitively, and performs the appropriate action, straightaway. There is no problem solving and reasoning that can be distinguished at this level of working. This is actually a very comfortable level to be functioning on, and a lot of practitioners do not progress beyond this point (Dreyfus 2003)
6. Master:	The master sees the standard ways of working that experienced practitioners use not as natural but as contingent. A master displays a deeper involvement into the professional field as a whole, dwelling on success and failures. This attitude requires an acute sense of context, and openness to subtle cues. In his/her own work the master will perform more nuanced appropriate actions than the expert (Dreyfus, 2003).
7.Visionary:	The world discloser or 'visionary' consciously strives to extend the domain in which he/she works. The world discloser develops new ways things could be, defines the issues, opens new worlds and creates new domains. To do this a world discloser operates more on the margins of a domain, paying attention to other domains as well, and to anomalies and marginal practices that hold promises for a new vision of the domain.

Figure 12 Levels of expertise.

The third category of expertise, 'Competent', reflects a significant deepening and widening of skills in relation to the previous two categories. As a result of considerable time in the field, the competent practitioner has sufficient knowledge and experience not only to select relevant and appropriate solutions, but also to do so autonomously. Due to the responsibility attached to this autonomy allows the competent practitioner to seek more creative solutions than simply following maxims allows. Although the competent practitioner has the self belief to attempt a creative solution, their attempts will often be based on a trial and error basis. This underlines the need for more learning and reflection before the competent practitioner can move into the proficient category. As pointed out earlier, the learning attitude of the practitioner is one of the key competences which are necessary to work on a better collaboration between the different practitioners. For the purposes of the current research, we can now draw a line under category 3: The assumption taken in this research is that competent workers represent the minimum level of expertise required to complete the tasks set in the research.

Although competent practitioners are defined as minimum level to be part of the Design Team, this should not imply that practitioners who exceed the category of competent should be refused as a member of the Design Team. It can be argued that in practice it should not be presumed that the majority of the practitioners working in the field will exceed the level of competent. Thus, any assumption or analyzes in this research project must focus on practitioners with a competent level of expertise. Another point is that if the problems defined can only be dealt with by practitioners from a broader level: between the proficient to the visionary level. This would imply that analyses to find evidence for answering the Research Questions will be a long and arduous process. Finally, and perhaps most controversially, if the practitioners working in the field in the status quo predominantly exceeded the level of competent, it is arguable that the problems identified in the status quo would not exist in the first place, at least not to the extent that they do.

Now the focus can turn to the 4th sub-question:

4. How can the level of expertise of Architects and Contractors be guaranteed?

Since there is no suitable method available to ensure that the professional practitioners possessed the required level of expertise, an indirect approach needed to be taken. In line with DRM, this approach involved making a number of assumptions based on the previous work of the BS research group. A shared belief in the BS research group was that for the sake of safety, in calculating markers for competence in this research it was better to overestimate than underestimate. The assumptions that were made were based on the BS research group's experience and knowledge of the different roles and responsibilities typically found within project teams.

Using the levels of expertise listed above as a guideline, the BS research group sought to provide reasonable estimates for the length of time required to safely reach the border between "Competent" and "Proficient". In essence, this border was chosen because ideally the practitioners in the research should not be classified as minimally competent, rather they should be fully competent.

The first set of assumptions made related to the novice category. This category was seen to represent something like an apprenticeship period in the field. It was further assumed that the novice would not be expected to shoulder much real responsibility for project decisions or tasks, and that what experience was gained would be minimal and second hand experience. This apprenticeship period was estimated to generally last for around 2 years.

Following this apprenticeship period, the novice could be seen as graduating to the advanced beginner category, in which an increase in responsibility can be expected. However, with only two years or so of second hand experience, it is unlikely that the advanced beginner will be granted the autonomy required to plan project strategy or execute project decisions. It is much more likely that the responsibilities of the advanced beginner will be planned and monitored by more senior project managers. In this sense, the experience gained in this stage can also be viewed to a large degree as

second hand. It is estimated that this process of monitoring will typically be seen as necessary for a period of about 2 years before the advanced beginner is trusted with the responsibilities associated with the “Competent” construction project professional.

Once the professional has graduated to the category of competent, it is expected that s/he will occupy a responsible, managerial position within projects. As such, the competent professional will gain first-hand experience in both project planning and execution. It is important to point out, however, that once a professional enters this category, s/he has merely reached the level of minimal competence. In order to be classified as fully competent, a substantial amount of learning by doing is necessary. It is assumed that two full project cycles represent a reasonable timescale for this learning to take place. In addition, it is assumed that in many cases, the competent project profession will be involved in more than one project at any one time. Typically, projects last in the region of 2-3 years. Thus, for the sake of safety, it is estimated that six years of experience in this stage will allow the professional to be categorized as fully competent.

Now the 4th sub-question can be answered. The following consideration was taken into account; the estimation of the time required to reach a fully competent level amounts to the sum of the expected durations of each of the relevant categories. It was estimated that the novice category would last approximately 2 years; the advanced beginner would last a further two years; and moving from the lower to the higher end of the competent category was estimated at around 6 years. The final estimation then was that 10 years of experience was a necessary prerequisite for practitioners to participate in the workshops in the current research. This criterion of 10 years was communicated to the professional bodies (TVVL, BNA, Het Hellend Dak and Vebidak) responsible for providing the practitioners. In effect, the agreement of the professional bodies to select only practitioners with at least 10 years of experience provided an objective guarantee of the expertise required.

To generate a clear picture of what types of knowledge and skills the practitioners from each discipline were expected to possess, the competence profiles of the professional bodies supplying the practitioners were reviewed in detail and used later in the research to help analyze the results. The competence profiles in sub-question are as follows:

BNA (Dutch Professional Organization Architects) / 2009; level: K, L, M, N (Architects: designers)

- EVC (Professional Qualification based on a Curriculum Vitae) + Hoofd Bedrijfsschap Ambachten (HBA; Professional Oranization Crafts Industry) + Bouwradar / 2009; level: Company manager (roofers; Contractors)

- Rijnland Advies + TVVL (The Dutch Society for Building Services) / 2008; level: Company manager / head of internal + external operations (installers: Contractors)

With the use of these competence profiles specific areas of disciplinary knowledge could be determined, related to object- and realization-knowledge. As argued in Chapter 1.4, object- and realization-knowledge are represented by function-types. The function-types are all relevant items that must be incorporated in the product for the design task, or essential items that the design has to fulfill. Object- and realization-knowledge is part of the competences of both Architect and Contractor, with for each competence a stress on one of the knowledge-types. Therefore knowledge-types and related function-types can be organized in a reference-list which refers to the discipline areas for Architects and Contractors.

In the Appendix 2 (page 5 – 7) a total overview is given of these competence profiles. The most important aspects are related to the items; process, role / responsibility external, complexity, quality process and results, competences (expertise).

KEY-COMPONENT C3: PRACTICE SETTING

As mentioned in Chapter 1 the major motivation for the current research project is that there is a lack in practice of Collaborative Design scenes were practitioners – Architects and Contractors – can interact and exchange object- and realization-knowledge working on design tasks to produce Integral Designs that comprise realization-knowledge. There is such a lack of collaboration in the status quo that it is not possible to directly observe and study collaborative teams working on roof designs in practice. This of course presented a problem for the current research. With this problem in mind, a simulation of the desired collaboration needed to be devised.

In order to work towards a solution to the lack of collaboration, while at the same time live up to the standards of academic research, the following sub-question needs to be answered:

> *5. What kind of setting would be appropriate for the practice of Collaborative Design and also for the analysis of the research?*

In order to arrive at a reasonable answer the following additional sub-question is needed:

> *6. What type of collaboration has the best focus compared to practice, and thus is the most appropriate for the Technological Design to be applied in practice in the near future?*

Additionally to the studies discussed in Chapter 1.2 about the richness of communication (page 22) the following aspects can put forward. The basis for the setting for Collaborative Design is the improved possibility to exchange knowledge between the practitioners. Knowledge exchange in small groups or teams is based on the ability and competences of the team members to communicate formal and informal (Dainty et al. 2006) in such a way that the design can be executed integrally with the necessary and sufficient understanding of the group members. Communication might be understood as the flow of information between the group members, being sender and receivers as formulated by Shannon and Weaver (1949) to get mutually the right understanding of the design to produce.

Although many new tools and methods to facilitate communication have become available in recent years, there is still considerable debate as to their efficacy. For instance, much research suggests that new media tools can act as a significant barrier between members of a team (Daft & Lengel 1984; Majumder 1994; Eastman 1996; Sproull & Kiesler 1998; Gabriel & Maher 1999; Ahmed et al. 1999; Boujut & Laureilard 2002; Abadi 2005). In addition, the inclusion of these new media tools has in many cases led to an increase in geographical distance between what is known as “co-located” teams. On the basis of a ten-year review of co-located research, Olson and Olson concluded that “distance … matters” (2000). What motivated the development of these tools was the desire to enable distributed teams to jointly working on a task. Each of these tools is developed for use of a particular medium. However, much recent research has concluded that each medium brings with it its own restrictions (Gabriel 2000; Boujut & Laureilard 2002; den Otter 2005; Emmitt & Gorse 2007; Emmitt & den Otter 2008). Related to the richness of communication the face-to-face interaction and sketching are still the most important tools for developing and solving problems (Gann & Salter 2000; Salter & Gann 2002) related to the richness of information (Cockburn 2002).

The “immediacy” provided by a face-to-face setting has been shown to be an important element in solving problems in complex situations (Elliot 2000). The explanation for this effect of immediacy on problem solving is that richness of information increases in communicative mediums commonly associated with face-to-face team work, as opposed to the mediums noted above that are used asynchronously by distributed teams (Daft & Lengel 1984; Suh 1999; Melnik & Maurer 2004). It can be concluded that the higher the level of abstraction and complexity of a given task, the more is the need for interactive knowledge sharing via direct verbal communication. As noted earlier, the tasks in the current research are characterized as highly complex, wicked problems.

As Emmitt and Otter (2008) explain, dialogues show to be a preferred means by design teams to communicate. However, the current research project does not wish to simply quantify how much communication takes place between team members; rather, it wishes to provide a picture of the nature of the knowledge exchange and interaction, by notation of both object- and realization knowledge between the practitioners by speech and on paper. It is assumed that this will enhance collaboration as the basis for an Integral Design. This is visualized by the modified communication model of Feldberg (1975) as discussed in Chapter 1.2 (see Figure 1, page 21). As described in Chapter 1.2, Communication in Collaborative Design processes, design communication showed to be more extended compared to normal communication. For that reason in this research project design communication is observed explicitly for the notated artifacts of the design (design output) by sender and receiver based on their notated field of experience (knowledge exchange). The fields of experience are related to the object-knowledge of the Architect and the realization-knowledge of the Contractor. By organizing a face-to-face setting between these two practitioners with these characteristics, it is assumed that interaction and knowledge-exchange can be stimulated using a supportive tool.

Thus, the answer to the 6th sub-question is that rather than attempting to deal with the extra complexity associated with co-located teams, the organization of the Collaborative Design teams is best done in a face-to-face setting. This determination was made based on the following sub-question:

> *7. What kind of setting for the Collaborative Design teams can be effectively managed within the current PhD research project?*

In Chapter 1.2 different aspects which were studied in relationship to levels of communication (page 21) and scenes and richness of communication (page 22) were already pointed out and the Workshop as an appropriate Collaborative Design scene. Since it has already been noted that face-to-face Collaborative Design teams are not the norm within current practice, a working setting needed to be devised that could lead to a number of important Goals. First, the setting needed to facilitate face-to-face communication within the collaborative teams. Second, the setting needed to allow unobtrusive observation for the research. Finally, the setting needed ideally to serve as a learning tool for both the practitioners and the research.

The latest examples of research of the BS research group can be seen as extensions of earlier work conducted between 2000 and 2003 at the Technical University of Delft, which are described in (Quanjel and Zeiler 2003, 2009). Here, the design of the research setting was based on the arguments of Schön (1987) that a “practicum” represented a “learning by doing” approach, as a useful method to train practitioners to work in a collaborative way in practice. In methodological terms, the practicum can be classified as a semi-experiment (Campbell 1971; Yin 2003). This led to the Delft research designing a workshop setting to allow practitioners from different disciplines to better learn how to collaborate within projects.

In order to confirm the usefulness of the workshop setting, six pre-test workshops were organized, each of which contained 25 practitioners. The results and feedback from these professional workshops was in line with the findings of the earlier expert workshops. One of the end results of these two workshop settings was a final report (Quanjel & Zeiler 2003, 2009) submitted to the Professional Organizations. A key recommendation of the report was that future collaborative work is well served by using a face-to-face medium. The organizations in sub-question agreed with this recommendation to such a degree that they subsequently adopted the approach in their own professional training. The results of this research and the feedback received from these practitioners were both similarly positive.

The present research project, then, retains the earlier approach and serves to extend the findings of the Delft research. Essentially, it was necessary to organize and develop recent examples of BS research in such a way so that the totality of BS research findings could provide a fuller picture of the

problems within the design process in the status quo. This was done in order to improve the efficacy of the solutions that the BS research group has developed. Thus, like the work of Savanović (2009), the current research project also chose to retain the workshop setting. In this research the workshop setting is executed as a Collaborative Design Workshop.

KEY-COMPONENT C4: DESIGN SUPPORT TOOL

One of the starting assumptions of the BS research group in general and of this research in particular is that *Multidisciplinary design teams will need significant support in order to collaborate effectively and thus produce Integral Designs.* This is based on two prior conditions for multidisciplinary design: practitioners need to gain greater acquaintance of each other's knowledge and subsequently, practitioners need to use a language and representation that can be shared by the other discipline(s). Another consideration was that the developed approach should be effective enough to be applied by Collaborative Design Teams that consist of members from different disciplines with varying degrees of education. One key area of support considered necessary was the development of Design Support Tools that allow the Collaborative Design teams to provide Integral Designs for roofs.

Essentially, the tasks in the current research require the exchange of knowledge between the relevant practitioners identified. Therefore, sub-question 8 of the sub-questions needs to be answered:

8. What type of Design Support Tool is capable of capturing and structuring the knowledge exchanged between the different practitioners participating in the workshops?

Additionally to the characteristics of a support tool as defined by Lindemann et al. (2003), as discussed on page 23 in Chapter 1.2 specific aspects are discussed. The first requirement of a Design Support Tool is that such a tool needs to be sufficiently easy to use and should not hinder the task realization. The Design Support Tool should also have the characteristics to give the users the possibility to give insight into each others' knowledge in an explicit way, to share within the team and between teams. Because the CD teams involved have different educational background and represent different knowledge-types, object- and realization knowledge, the tool has to facilitate the use and development for different levels of abstraction to different types of users.

In addition to the role of the tool during the knowledge exchange within the workshops, the tool also needs to allow analyzing the knowledge exchange after finishing the workshop in order to draw conclusions regarding the success of a workshop. In order to successfully develop the research approach envisaged, it was necessary to use the same tool during both the actual knowledge exchange during the collaboration and in the analysis stage of the research project.

As stated earlier, the current research project was executed within the BS research group. The group was set up out of the previous work of Zeiler (1993, 2007), which was motivated and based upon Methodical Design. Focus for the Methodical Design is the desire to understand the relationship between the function-types that a given design must include and the sub-solutions that can realize these function-types on various levels of abstraction. For this purpose, Methodical Design uses morphological tools, based on the morphological box designed by Zwicky (Zwicky & Wilson 1967). Modification of Zwicky's box was needed in order to provide a simplified tool that could be used to capture the function-types and aspects required and the knowledge contributed by the design teams for these purposes. The tools that were designed for this purpose were the Morphological Chart (MC) and the Morphological Overview (MO). The MO gives an opportunity to design teams to collect, notate and discuss in a methodical and structured way the different necessary function-types and related probable sub-solutions with different levels of abstraction to fulfill the design-task. Where the MC is used for individual use by the practitioners, the MO is used within or between teams. Within the BS research group the possibilities of the use of the MO with design teams, with practitioners with the same educational background, were part of the considerations to extend the use of the MO in another setting than design teams used (Savanović 2009; Zeiler et al, 2009; Zeiler 2007; Zeiler 1993).

Although the MO is part of the Methodical Design, which is based on international references (p 41), it is correct to distinguish the use of the MO for different purposes. Therefore it is important to point out the difference between the use of the MO as support tool to develop a single product or a building. Where a product can inhabit a set of functions (Rosenman & Gero 1998, page 336) and function-types. A building inhabits as an artifact a large amount of products or to be developed products. For product development the MO is used as one of the techniques in a set of activities or framework such as described by Smallenburg et al. (1996, p 346). In this framework the MO is only used to search for solution-principles (Smallenburg et al. 1996, p 348) and additional techniques are used to develop and define the functions, the function-structure and materialization.

In the current research project the analyses of the functions and the establishment of a function structure is done through the analyses of the function-types for an Integral Design, related to the object- and realization-knowledge, complemented with the Competence Profiles of the Professional Organizations of the practitioners involved. The result of these analyses is a reference-list as presented.

In a Collaborative Design Workshop teams inhabit practitioners with object- and realization-knowledge, using different levels of abstraction, with the aim to work collaboratively on Integral Designs. The characteristics of the MO should be appropriate to fulfill the requirements as a Design Support Tool for both Architects as Contractors.
Thus, based on the answers to sub-questions 1 to 8, it can be concluded that the MO is a useful Design Support Tools that can be used by a CD Team to structure and organize knowledge while working on a Design Task. Therefore, the MO is an appropriate choice for use with the practitioners in the research. However, for the specific purposes of the present research, which morphological tool or combination of tools to use still needed to be determined.

Whereas in Savanović (2009) the MC was used as a precursor to the use of the MO, in the current research project the direct use of the MO was considered more productive. The reason for this is, in the current research project the design tasks were more specific and the practitioners involved included practitioners that were more practically based and educated differently. This is most noticeable in the roofers and installers in the current research, whose education is far more practically based than, for example, the building physics or structural engineers present in the work of Savanović (2009).

Another key departure from Savonović (2009) is that in his work the individual practitioners were expected to take an active role in working on solution(s) of the design task, in contrast to the status quo in which the Architect's original design sketch dominates the problem and restricts the possible solution(s). Alternatively, in the current research project only the Architect could be expected to begin the process of defining the design, and the role of the Contractor was to impart realization-knowledge to help the Architect determine whether the design suggestions were indeed workable in practice. Therefore, the most efficient way to achieve this Goal was to precede with each of the design team members working on the same MO from the outset. The MO should be presented as a tool which can help the practitioners to structure, discuss and develop the necessary function-types and sub-solutions related to the design task in a more methodical way. This approach is hoped to enlarge the chance of capturing those function-types and sub-solutions that are necessary to form the basis for an Integral Design.

Based on the above the Morphological Overview (MO) is chosen as the Design Support Tool to be used in the workshop-series number WS01 to WS05 and in the definitive workshops DWS01 and DWS02. The MO also turned out to be a very useful tool to analyze the team contributions.

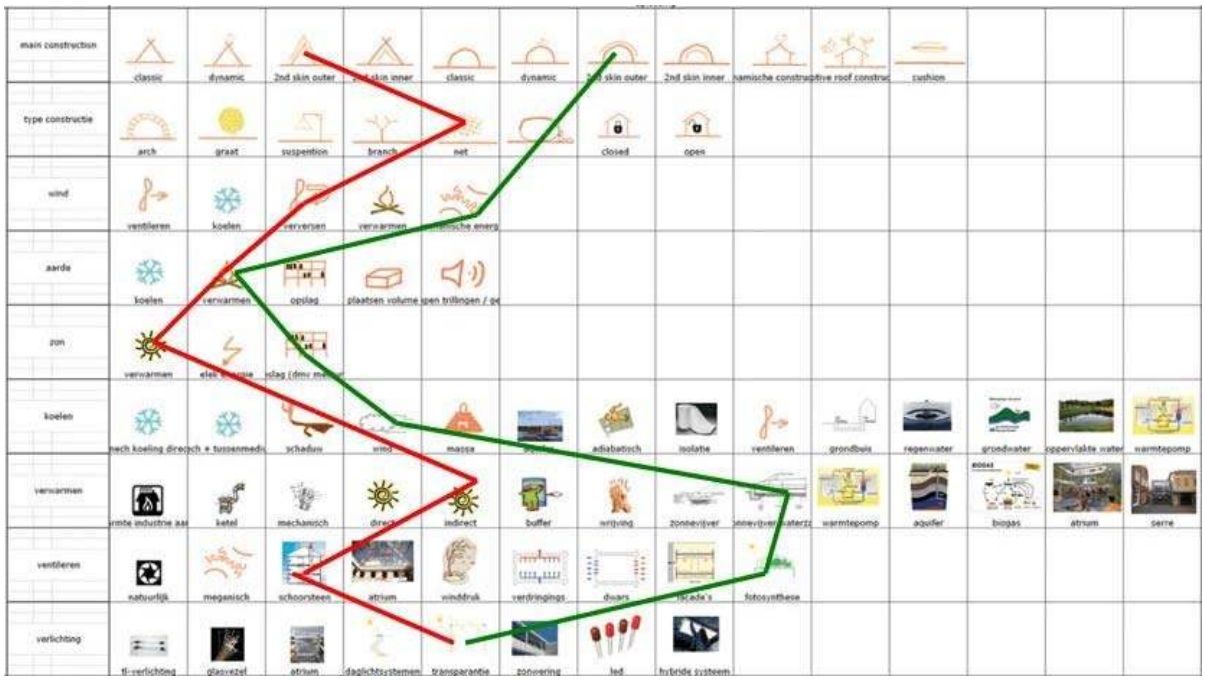


Figure 13 Example of a Morphological Overview.

The construction of a Morphological Overview (MO) is structured like a matrix: on the vertical axis of the MO the required function-types should be listed. On the horizontal axis possible sub-solutions for these function-types or aspects are listed (e.g. construction, cooling, heating etc.). In Figure 13 the red and green connection-lines are possible combinations of sub-solutions as part of the design. The purpose of the vertical list is to try to establish those essential aspects that must be incorporated in the product, or essential function-types that the design has to fulfill. They should cover all the necessary function-types and the main aspects to consider for the product/building to be designed.

Now the four key-components which influence the Collaborative Design Workshop are defined: Design Task, Collaborative Design Team, Practice Setting and Design Support Tool (Morphological Overview). As part of the development of the Collaborative Design Workshop in the next DRM stage the next steps are:
- To develop realistic/authentic tasks
- To organize competent teams
- To develop a setting that stimulates knowledge exchange between the practitioners, while also providing a suitable setting for observation
- To develop a tool to structure the knowledge exchange and management for the practitioner, and which also aids the research in the analysis of the team contributions

GOAL 3: DEVELOPMENT OF THE RESEARCH QUESTIONS RQ5 TO RQ9

The Research Questions RQ5 to RQ9 are based and related to the developed key-components to identify the effect of the key-components in the Collaborative Design scene: the Collaborative Design Workshop. Therefore in the next section the Research Questions are formulated based on the related four key-components.

KEY-COMPONENT C1: DESIGN TASK

Since a starting assumption of the research is that the more complex the task, the more the need for collaboration in order to provide a satisfactory solution, it was important to determine that the tasks set

in the research were sufficiently challenging for the design teams. This question is addressed initially in workshop series 03 (WS03). The research question is therefore formulated as follows:

RQ5 *Were the tasks sufficiently complex to require collaboration between the practitioners?*

KEY-COMPONENT C2: COLLABORATIVE DESIGN TEAM

Since the Goal of the research is to develop a Collaborative Design Workshop with Practice Setting to stimulate and observe interaction- and knowledge exchange on complex design tasks for Integral Designs for roofs it was considered crucial that the design teams in the research were composed of 'competent' practitioners. It was important to avoid a situation where a number of the design teams included individuals who could not make enough productive contributions due to a lack of knowledge and experience. In addition to the screening of the professional bodies, the competence of the team members is judged on the type of contributions made. Related to the definition of Integral Design this means contribution of object- and specific realization knowledge. Because the Architect is one of the team-members it can be expected that the Architect should put forward object-knowledge and the Contractor realization-knowledge. As for the realization-knowledge should be part of the Integral Design for roofs, this implies that Architect as well as the Contractor could and should notate realization-knowledge. Although both types of knowledge are part of the Integral Design and also monitored, because of the research project focus the Research Question is therefore formulated as follows:

RQ6 *Did both types of practitioners succeed in contributing realization knowledge?*

KEY-COMPONENT C3: PRACTICE SETTING

A starting assumption of the BS research group, which was borne out in previous research and in the literature, is that a face-to-face setting is a productive environment for a team to collaborate on a task. This implies that the face-to-face setting is collaborative when there is interaction and knowledge in speech, notations in sketches or the Morphological Overview about the design-task between Architect and Contractor. The focus although is on explicit notated notations, sketches on paper or in the Morphological Overview. The workshop format used in this research project is chosen because it provides a face-to face setting that can realistically be observed and later analyzed. Whether the workshops took place at the university or in a company setting, a commonality of all of the workshops is that they were conducted in conference rooms. The Research Question is therefore formulated as follows:

RQ7 *Did the face-to-face setting provided by the workshop allows collaboration between the practitioners working on the design task?*

KEY-COMPONENT C4: DESIGN SUPPORT TOOL

The Design Support Tool is arguably the most significant key-component of the Collaborative Design Workshop. The assumption in this research project is that the Morphological Overview (MO) as a Design Support Tool can help focus the teams on the problems of the design task and to encourage the necessary contribution of object- and realization knowledge of the two practitioners. The two Research Questions relating to the Design Support Tool are as follows:

RQ8 *Did loose introduction of the Morphological Overview lead to acceptance of the tool by the practitioners?*
RQ9 *When used, did the Morphological Overview allow the exchange and structuring of knowledge between the practitioners?*

3.2.2 OUTCOMES FOR GOALS OF DESCRIPTIVE STUDY 1

Related to the three Goals for the Descriptive Study 1 the subsequent outcomes can be presented.

OUTCOME 1: ANSWERS TO RQ3 AND RQ4

From the analyses of the Case Studies and additional literature studies the answer to the related Research Question RQ3 can be answered.

RQ3 *What factors hindered the success of the Case Study projects?*

A RQ3 In summary, the three Case Studies suffered mainly from the same two primary causes. These main causes identified as a lack of competence, poor knowledge- exchange and structuring, which led to significant failures in all three projects. In order to seek workable remedies for these causes of failure, a further literature review was conducted.

OUTCOME 2: KEY-COMPONENTS IDENTIFICATION

With the results of the Case Studies, experience from practice and literature studies the key-components and the answer to the Research Question can be presented as outcome 2.

RQ4 *What are the necessary key- components of the Technological Design?*

A RQ4 The necessary key-components that are assumed to be most important in the Technological Design are as follows: Design Task; Collaborative Design Team; Practice Setting; Morphological Overviews.

OUTCOME 3: RESEARCH QUESTIONS RQ5 – RQ9

Related to the identified key-components the following Research Questions could be formulated to identify the influence of these key-components in the Collaborative Design Workshop.

RQ5 *Were the tasks sufficiently complex to require collaboration between the practitioners?*
RQ6 *Did both types of practitioners succeed in contributing realization knowledge?*
RQ7 *Did the face-to-face setting provided by the workshop allows collaboration between the practitioners working on the design task?*
RQ8 *Did loose introduction of the Morphological Overview lead to acceptance of the tool by the practitioners?*
RQ9 *When used, did the Morphological Overview allow the exchange and structuring of knowledge between the practitioners?*

3.2.3 OVERVIEW DRM STAGES, THE CORRESPONDING RESEARCH QUESTIONS AND GOALS

With the outcomes of the Descriptive Study 1 three Goals where reached. First, the problem is expressed in practice. Second: the key-components could be identified. Third: Research Questions could be formulated to identify the influence of the key-components in the Collaborative Design Workshop. The Descriptive Study 1 is now finalized, in Figure 14 this is showed by marking this DRM stage yellow.

In the next DRM-phase the identified key-components (Design Task, Collaborative Design Team, Practice Setting, and Morphological Overview) have to be developed to answer the Research Questions related to these key-components. This is done through research improvements which have to deliver results from analyses and evaluation of the application of these improvements in developed workshop series. The DRM-overview of Figure 14 gives an overview of this specific DRM-stage – the

Prescriptive Study – related to the other stages. For each workshop series in the Prescriptive Study the related Research Questions are organized next to the related Goals.

	DRM Stage	Research Question(s)		Goals
1	**Research Clarification**	**RQ1**	*What type of knowledge should the competent architect, roofer and installer possess?*	Problem identification +answers RQ1-RQ2
		RQ2	*When and how should this knowledge ideally be exchanged within a Collaborative Design Team?*	Development of RQ3 and RQ4 Hypotheses and Measurable Success Criteria
2	**Descriptive Study 1**	**RQ3**	*What factors hindered the success of the case-study projects?*	Problem is expressed in practice Answers to RQ3+RQ4
		RQ4	*What are the necessary key-components of the technological design?*	Key-components identification Development of RQ -5-6-7-8-9
3	**Prescriptive Study**	**RQ5**	*Were the tasks sufficiently complex to require the collaboration between the practitioners?*	Pre-Answers to: RQ -5-6-7-8-9 Research Improvements
		RQ7	*Did the face-to-face setting provided by the workshop allows collaboration between the practitioners working on the design task?*	
		RQ6	*Did both types of practitioners succeed in contributing realizations knowledge?*	
		RQ8	*Did loose introduction of the Morphological Overview lead to acceptance of the tool by the practitioners?*	
		RQ9	*When used did the Morphological Overview stimulate for the exchange and structuring of knowledge between the practitioners?*	Development and application of the Collaborative Design Workshop lay-out Finalizing of Research improvements
4	**Descriptive Study 2**	**Test RQ 1-9**		Answers to: RQ5-6-7-8-9 Testing the Key-components and Research improvements in the Definitive Collaborative Design Workshop Verification of the Key-components and the analyzing tools Evaluation of the Hypotheses and Measurable Success Criteria

Figure 14 DRM-stages with corresponding Research Questions and Goals.

3.2.4 DISCUSSION AND EXPECTATIONS FOR THE NEXT DRM STAGE

In the previous stage of the DRM the key-components of the Technological Design are addressed. The following discussion about some general expectations will provide the reader a better perspective on the results of the various workshops executed in the next DRM stage, the Prescriptive Study.

Since the Collaborative Design Workshop as applied involves practitioners from different educational and professional backgrounds, it cannot be not expected that there will be equal contributions from all participants. Both participants in a team have to contribute object- and realization-knowledge in the conceptual phase of the design process in order to produce an *Integral Design for roofs* as result. Contribution is defined as the result of interaction and knowledge exchange of participants within the Collaborative Design Workshop.

The Collaborative Design Workshops that will be executed in the Prescriptive Study require a Collaborative Design Team to decompose the design task into function-types for which the team has to provide corresponding sub-solutions that can be adequately realised. As such, it is reasonable to expect the team discussions to be episodic in nature, with one episode devoted to a particular function-type, sub-solutions related to the design. These function-types, sub-solutions may be

returned to throughout the discussion, and they may at times overlap or interject between other episodes. No matter wich type of practitioner leads the discussion, it is expected that within these discussion both object -knowledge and realization-knowledge will be exchanged and notated. In fact, the success of the Collaborative Design Workshop depends on the multidisciplinary team members being able to interact and exchange the knowledge types associated with their respective practitioners.

In order to gain a clear understanding of the expected knowledge of the professions within the research project and all relevant and necessary function-types for an Integral Design, the Morphological Overview (MO) is used in this research project. This is an additional use of the MO, beside of the function as a Design Support Tool. Because of the characteristics of the MO, to structure items of different abstract levels, it is also an appropriate tool to structure and analyze the notated function-types and sub-solutions by the different practitioner-types within the different Collaborative Design teams.

To develop this content of the MO as an analyzing tool and related to the framework by Smallenburg et al. (1996) two steps are used as the basis for this content; analyzes of the functions (Vliegen et al. 1991) and establishment of the function-structure (Roth 1982). The functions and related function-types were developed on the basis of the analyzes of the competence profiles relating to the relevant Professional Organizations. These competence profiles cover the necessary knowledge and skills related to the practitioner types involved. The competences of Architects and Contractors complementary inhabit the necessary knowledge and related function-types for an Integral Design for roofs. The developed function-structure therefore is the basis countercheck the reasonable expected contributions in the design sessions by the practitioners involved. The result of this study was a function-structure which is organized into a list of function-types that distinguished between object-knowledge and realization-knowledge, reflecting the expected knowledge of the Architect and Contractor respectively which is necessary to develop an Integral Design. This reference-list and related function-types are used as the content of the MO to analyze contributions of the different practitioners in the subsequent workshops.

These function-types are presented in Figure 15 the definitions of these function-types can be found in Appendix 3. The function-types relating to object knowledge begin with ‘rain/waterproof’ and end with ‘operational’. The remaining function-types represent the expected object knowledge. Presented here is the final used Reference-list for the function-types, which was used when all up-to-date information was available. This table was used in WS05 and the definitive workshops DWS01 and DWS02.

In Figure 15 The upper part, within the green box, are realization-related function-types (11 items: Rain/ water proof – Operational), the lower part in the yellow box are the object-related function-types (14 items: Light / sun-use and protection – Flexibility). The total list has 25 function-types as listed in the left column.

WS: Team: Task: Functionalities / Solutions		
Rain / water proof		
Temperature proof		
Ventilation		
Maintenance		
Safety		
Heating & Cooling		
Sustainable energy generation		
Construct & Build		
Comfort & heath		
Accessibility		
Operational		
Light / sun-use & protection		
User space / functions building & roof		
Orientation & sight		
Construction		
Costs & finance &benefit		
Architecture		
Sustainability		
Building Physics		
Fire protection		
Utilities		
Shape		
Material		
Users		
Flexibility		

Figure 15 Morphological Overview (fragment) used for Analysis Format.

It can be expected that the practitioners are competent when their contributions include the function-types as presented in the above reference list. As stated before, in a Collaborative Design Workshop it is plausible that because the Architect is part of the CD Team object-knowledge should be contributed. More important to solve the problems from practice is that Architect and Contractor will contribute complementary realization-knowledge within the Collaborative Design Workshop as a basis for Integral Designs for roofs. If the Collaborative Design Workshop makes it possible that both practitioners interact, exchange and contribute realization-knowledge this is an indication that they are competent or the Collaborative Design Workshop can be the setting to work on their competence.

3.3 PRESCRIPTIVE STUDY

The main Goal of this DRM stage, the Prescriptive study, is to develop research improvements: observation formats, analyzes formats and evaluation formats by a sequence of developing, applying and improving such formats related to the four key components in semi-experiments. In this way the Collaborative Design Workshop, incorporating the four key-components and the related analyzing formats are developed and applied in this stage as a useful scene to interact and exchange knowledge between practitioners, which can be tested in the final DRM stage.

A second related Goal is to show the effect of the application of the four key-components in the Collaborative Design Workshop to be able to measure knowledge exchange and interaction between the practitioners. This is done by the development and application of research improvements. At the end of the Prescriptive Study these research improvements have to be finalized so they can be tested in the final DRM stage.

The key-components as identified before are: Design Task; Collaborative Design Team; Practice Setting; and Design Support Tool. Related to the key-components the next issues are leading in this research stage:
- To develop realistic/authentic tasks
- To organize competent teams
- To develop a setting that stimulates knowledge exchange between the practitioners, while also providing a suitable setting for observation and analyzes.
- To develop a tool to structure the knowledge exchange for the practitioners which also supports the research in the analysis of the team contributions.

To work towards each of these issues requires observation, analyzing and evaluations formats. These formats are developed and applied in the consecutive steps throughout the Prescriptive Study.

In this stage five workshop series are executed in which the results of the first workshop is used in the second series and so on, the stage is divided into sub-stages,. In each sub-stage a series of workshops took place. So, per section for each Workshop series the Answers and Results are provided and finally the Outcomes of the Prescriptive Study.

Since the Collaborative design workshop needs to be developed for practitioners, it is important that the workshop series are executed with two types of practitioners with at least 10 years of practical experience to be able to interact and exchange object and realization knowledge for a Design Task. As written in Chapter 3.1.2 it was possible to secure such practitioners with the cooperation of the Professional Organizations of the involved practitioners. Through successful negotiation with the Professional Organizations, three workshop series (WS03, WS04 and WS05) were organized. Due to this necessary cooperation, the research was limited in the amount of practitioners and in the timeframes they were available in large enough pools. However, to avoid a lack of practitioners needed for the development and application of the Collaborative Design Workshop, two pre-test workshops were executed with students; WS01 and WS02.

The first two of these workshop series, WS01, and WS02 took place in October, 2005 and October 2006. These workshops functioned as pre-test workshops in order to verify research improvements related to two key-components of the Collaborative Design Workshop. First; evaluation of the general Practice Setting and second: the initial approach to the formats for observation, analysis and evaluation. The analysis and observation format is iteratively improved throughout all of the workshop series.

The three workshop series, WS03, WS04 and WS05, took place between June 2007 and June 2008. These workshops were used for the introduction and development of research improvements related to the key-components of the Collaborative Design Workshop within the Prescriptive Study stage: Design Task, Design Team, Practice Setting and Morphological Overview. In order to provide the workshop observations with the right focus, and to organize the analysis, the development of the key-components was distributed through workshops WS03 to WS05. WS03 focuses on interaction between team members in the Practice Setting and the Design Task related to Research Question; RQ5 and RQ7, while WS04 focuses on contributions within the CD Team and adoption of introducing the support tool to the design teams; RQ6 and RQ8. Finally, WS05 focuses on the contributions of the individual practitioners, working together using the Morphological Overview; RQ9.

3.3.1 WORKSHOP 01

The first workshop series, WS01 functioned as a pre-test workshop, as described above.

For the pre-test workshops WS01 and WS02 students were asked to apply. They served as guinea pigs before practitioners were asked to participate in the workshops. The reasons for using students are: First, the setting of workshop needs to be developed and applied before presenting the workshop to the practitioners. Second, only a limited number of practitioners are available and by using practitioners for the pre-testing, a lower number of practitioners are available for the real tests. Finally because the workshops could be organized with the TU/e, this was relatively easy to manage.

The students that took part in these workshops had different educational backgrounds drawn from various educational institutes in the Netherlands on middle (MBO), high (HBO) and on the scientific level (WO). The WO students played the Architect's role and were expected to possess the majority of object knowledge. The HBO and MBO students played the roofer and installer's roles and were expected to possess the majority of realization knowledge. Thus, it was possible in principle to develop and apply workshop setting.

WS01 was a two-day workshop that took place in a conference room at the Technische Universiteit Eindhoven (TU/e) on October 7 and October 24, 2005. Day 1 involved asking the design teams to work on the design task as a team, but without the Morphological Overview. On day 2, for reasons of contrast, the teams were introduced to the Morphological Overview (MO) and were asked to use it from the outset on a new design task and with new team members. A total of 18 students participated in the WS01. The participants were randomly distributed into six teams of three members, with each team consisting of one MBO, HBO and WO student. Two main Goals for WS01 were formulated: Goal 1 concerns the development and application of the workshop setting, and Goal 2 concerns the evaluation of observation and analysis formats used.

The task that was set during WS01 was to provide a design for a sustainable energy-roof for an existing office. Each of the two workshop sessions lasted for one hour.

As mentioned above, the pre-test workshops were conducted in order to allow getting an initial impression of how appropriate the workshop setting may be for the main testing. Two main areas of the research design were of specific interest. These two areas are Setting, and Formats of Observation and Analysis. For the pre-tests WS01 two Goals for research improvement were set:

Goal 1: Determine whether the workshop setting encourages interaction.
Goal 2: Determine whether or not the developed Observation Format 1, is a suitable tool for observation and analysis of the workshop sessions.

GOAL 1

Goal 1 was achieved as follows. Since the workshops in the research observed by workshop assistants it was possible to arrange feedback discussions between these observers to develop an initial informal assessment of the setting. They agreed unanimously that the setting proved to encourage the students to interact productively.

The first of the formal Formats developed was the pre-defined questionnaire, which was designed for the students to rate their satisfaction on a number of aspects of the workshops. The questionnaire format is shown in Appendix 13 (Figure 13.1, page 190). The relevant questions for current purposes are presented in Figure 16.

WS01	**Q1**	**Q2**	**Q3**
	What is your rating of the Workshop	How did you experience the collaboration within your team	Did the collaboration within the team result in synergy
AVERAGE DAY 1	**3,3**	**3,7**	**3,7**
AVERAGE DAY 2	**3,6**	**3,3**	**3,5**

Figure 16 Average outcome of Pre-defined questionnaire WS 01.

The rating system used was a standard 5-point Likert scale. The following rating where introduced to the practitioners and the score used for the researcher between brackets, 1: poor (2), 2: insufficient (4), 3: sufficient (6), 4: good (8) and 5: very good (10). As can be seen from the table above, the average score of the students was always above sufficient on each of the relevant questions. Although there is a slight decrease in the rating for the second day, where the tool was introduced, this is a clear indication that the setting was a stimulating and productive environment for the practitioners to work in.

However, it was also important to determine whether the setting also proved to be useful in terms of encouraging interaction within the teams. The main format used to make this determination was the Observation Format 1 which was devised by the BS research group.

The Observation Format 1 was developed to provide an analysis of team interactions by recording not only the interactions, but also who is interacting with whom and which student is dominant in the interaction within the 10-minute observation segments. In addition, the format requires the observer to record whether and how the interaction was recorded and by whom. An example of the instructions given to the observers is provided on the next page (Figure 17):

INSTRUCTIONS FOR THE USE OF THE OBSERVATION FORMAT 1. FOR WS 01

General items

Name monitor:

Number design-team:

Overview of disciplines on the table:

A = Student MBO

B = Student HBO

K = Student WO

Use of communication tools or design tools.

The overview can be used to get insight into the two different aspects related to the exchange of knowledge in the design team.

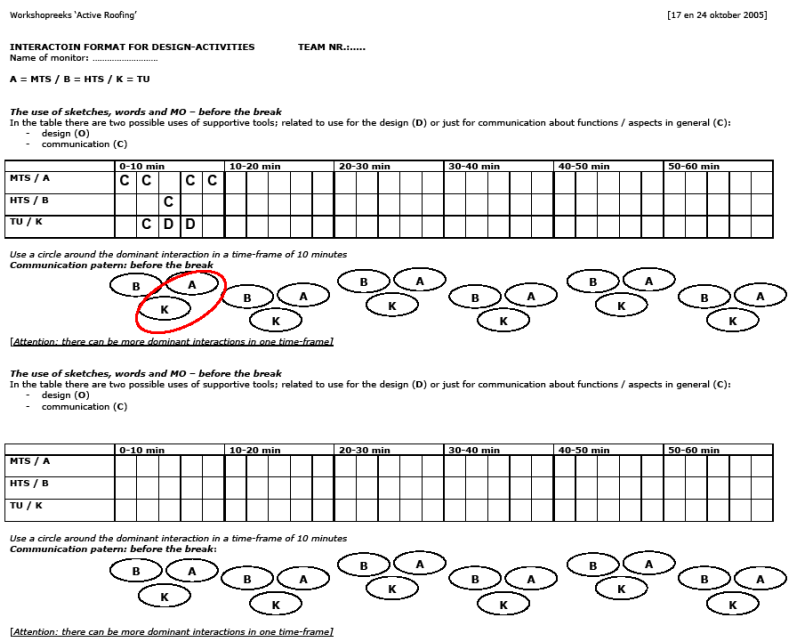
WHAT:

1. *Which discipline / participant uses language as a communication-tool to interact with other practitioners in the team about function-types / sub-solutions related to the design task (**C**)*

1. *Which discipline / participant uses a design-tool (drawing, schemes etc.) to notate function-types / sub-solutions / solutions related to the design task with other participant(s) within the team (**D**)*

HOW:

1. *Monitor and notate with an **C** or **D**, in time-frames of 5 minutes, who uses communication (**C**) or design-tools (**D**)*
2. *Notate, in time-frames of 5 minutes, who of the practitioners is most active with which of the other team-members – use an*



Workshopreeks 'Active Roofing' [17 en 24 oktober 2005]

INTERACTOIN FORMAT FOR DESIGN-ACTIVITIES **TEAM NR.:.....**

Name of monitor: .....

A = MTS / B = HTS / K = TU

The use of sketches, words and MO – before the break

In the table there are two possible uses of supportive tools; related to use for the design (**D**) or just for communication about functions / aspects in general (**C**):

- design (**O**)
- communication (**C**)

	0-10 min					10-20 min					20-30 min					30-40 min					40-50 min					50-60 min				
MTS / A	C	C		C	C																									
HTS / B			C																											
TU / K		C	D	D																										

Use a circle around the dominant interaction in a time-frame of 10 minutes

Communication patern: before the break

[Attention: there can be more dominant interactions in one time-frame]

The use of sketches, words and MO – before the break

In the table there are two possible uses of supportive tools; related to use for the design (**D**) or just for communication about functions / aspects in general (**C**):

- design (**O**)
- communication (**C**)

	0-10 min					10-20 min					20-30 min					30-40 min					40-50 min					50-60 min				
MTS / A																														
HTS / B																														
TU / K																														

Use a circle around the dominant interaction in a time-frame of 10 minutes

Communication patern: before the break:

[Attention: there can be more dominant interactions in one time-frame]

Figure 17 Observation Format 1 used for WS01.

In this particular pre-test workshop the observations were done by Master-students who were familiar with the Format before workshop WS01 was executed. One student was assigned to observe each team. A fragment of a completed observation form from WS01 is provided in Figure 18.

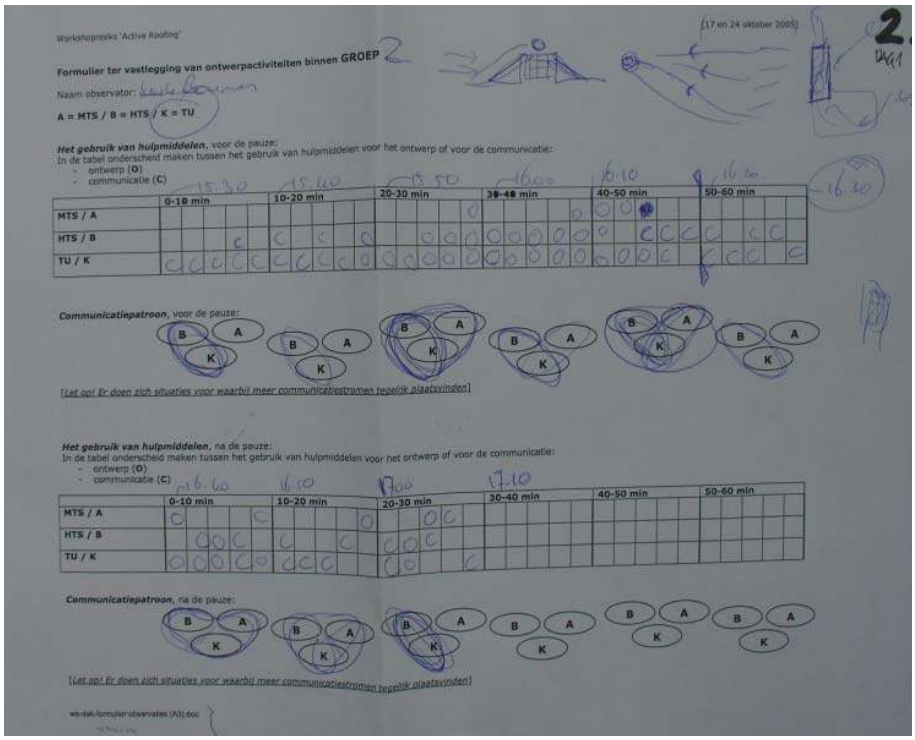


Figure 18 Example of used Observation Format 1 for WS01; in blue the used coding system during the design-session.

The Observation Format 1 is used to analyze the interaction between the students in WS01. The results show a clear pattern of interaction between the students as is shown in Figure 19.

Interaction between the role-types	Average percentage of combinations
MBO < > HBO	10 %
HBO < > WO	25 %
MBO < > WO	30 %
MBO < > HBO < > WO	35 %

Figure 19 Interaction as percentage of average combinations between role-types for students (MBO, HBO and WO) in the team.

The table in Figure 19 shows that the greater the distance between the individual educational backgrounds, the larger the amount of interaction that occurs. The amount of interactions is presented as the average percentage of combinations related to the total interaction-activities within the team. The first line of the table shows interaction between the two disciplines that are expected with the majority of realization knowledge. Line 2 of the table represents interactions between one of the disciplines associated with realization knowledge and the discipline associated with object knowledge. Significantly, in this situation the interaction increases by a factor of 2,5. The third line of the table essentially mirrors line 2 and shows a mix of realization and object knowledge. The outcome of the interaction is substantially greater than in line 1, and roughly equivalent to line 2. Line 4 represents interactions between the three disciplines. It can be argued that this represents the condition where

the maximum difference between the educational background and types of knowledge in the team is present. In this situation, the interaction is at its highest level.

Based on these outcomes it can be concluded that the first Goal is reached. The outcome confirms that this workshop setting encourages interaction. The outcomes also showed that the workshop is a suitable setting to encourage learning and to stimulate interaction between the different students.

GOAL 2

The second Goal was to determine whether or not the developed Observation Format 1 could be a suitable tool for observation and analysis of the workshop sessions. Therefore the Format should be able to visualize the interaction and to analyze the senders and receivers of knowledge (the Observation Format 1), thus allowing for the analysis of the flow of communication. This is considered to be a particularly important determination for two reasons. First, the Observation Format 1 was developed by the BS research group because previously used methods in the design research field are specific and time consuming particularly with the amount of sessions to compare (see section 2.4). Second, and related to the first point, since the Observation Format 1 was developed in-house there was no real experience of its use in practice. Thus, it was unclear how difficult other observers, not familiar with such approach, would find it to apply an observation tool during the workshops.

On the basis of the results of WS01, It was clear that the application of the Format was rather subjective. Since the observers needed to make on the spot judgment calls to determine the nature of the function-types in the team discourse, it could not be guaranteed that different observers would find the same things. Indeed, when the student observers submitted the results of their Observation Format 1 observations, great variance was found in the detail and quality of the observers.

Within the research the observers were reported to be obtrusive in the design sessions. This may have resulted from the close proximity that the observers needed to be in to use the Observation Format in the real-time setting. The fact that practitioners reported discomfort about the handling of observation in the workshops raised an important methodological concern; if the participants felt overly observed, then there is a danger that unwanted bias may be unintentionally created in the research subjects.

Analyzing the results of observations using the Observation Format 1 proved that it was difficult to use for the observers and not very precise to compare in the research. The observation ‘in action’ was experienced as too difficult for untrained assistants, especially since each of the observed teams comprised of three members. This left the risk of ‘missing’ important information during the design process related to the interaction and design. Additionally, there was the risk of influencing the design-team during their work. Third, it appeared that despite the introduction of the Observation Format to the students, the interpretation of the use influenced the results. With these restrictions in mind, the results of this WS01 are presented in Figure 20.

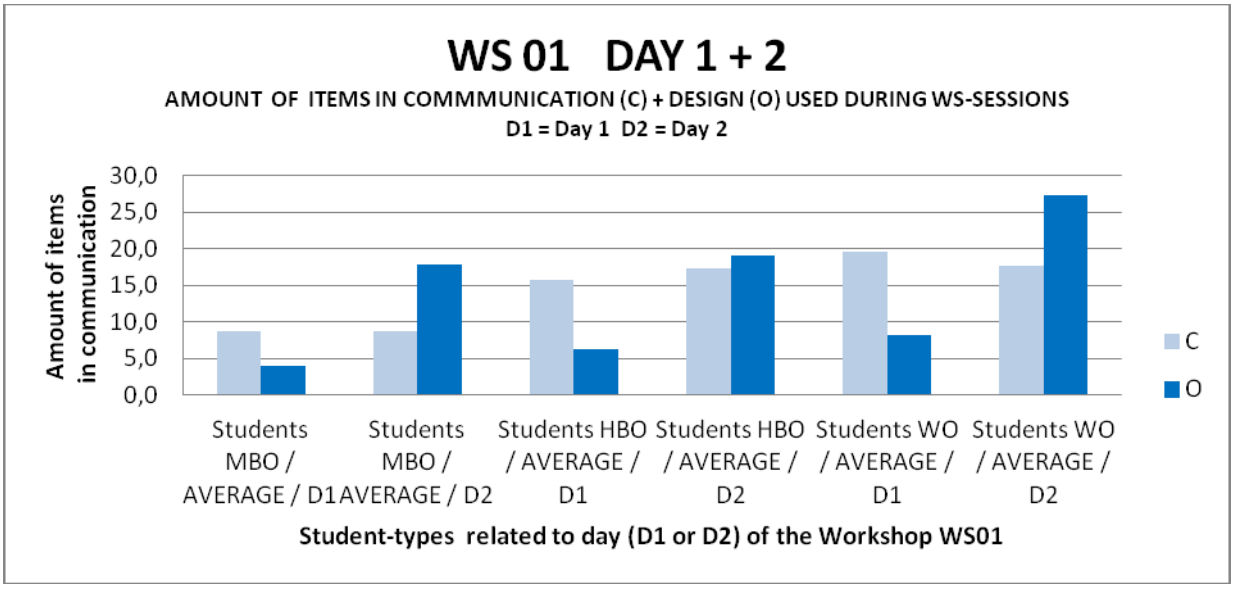


Figure 20 Amount of items in communication (C), design (O) used during the WS-sessions by student-types.

Figure 20 shows the communication, in amounts of used items, between the different participants with different educational backgrounds presented on the x-axis (MBO, HBO and WO-students). The average amount of observed communication (C) on the y-axis is fairly similar between the day 1 and day 2 setting. However, as can be seen, there was much greater variance in the average amount of design knowledge (O) that was actually notated or recorded in a sketch. Although not the focus in this WS-setting with students, because they cannot be compared with practitioners, the influence of the use of the Morphological Overview is clear. On Day 1 the Morphological Overview was not used, whereas on day 2 the Morphological Overview was introduced. For the different participants from MBO, HBO and WO there is the same tendency in the increasing average amount of notated design items on Day 2.

A final problem for the current research was that although the Format allowed the identification of communicative exchanges, the exact nature of these exchanges was not clear enough. This essentially meant that while it was clear that knowledge was being exchanged in the Workshop, it could not be said with confidence that the information recorded always represented the desired exchange of object- and realization knowledge is.

3.3.1.1 Results for Goals for WS01.

The first Goal was to determine whether the workshop setting could create a *scene* that encourages interaction. It can be concluded from the answers to the questionnaires and from the observations during the workshop that the workshop-setting is a potentially suitable scene to be used in the further research.

The conclusion for the second Goal *'if the developed Observation Format could be a suitable tool for observation and analysis of the workshop sessions*' is negative. The improvement of the research intervention of the observation Formats and analyses should be part of the subsequent workshops. For this improvement the following aspects should be taken into account. First, more focus needs to be placed on the consistency of the collected data of observation; second, the influence of the observation on the team must be minimized.

3.3.1.2 Overview DRM Stages, the corresponding Research Questions and Goals

With the results for the Goals from WS01 the next step for Prescriptive Study can be organized in WS02. This overview in Figure 21 is used in Chapter 3.3 and 3.4 to provide a summary and to show when research improvements are applied and its development during the research project (marked in yellow).

	DRM Stage	Research Question(s)		Goals
1	**Research Clarification**	**RQ1**	*What type of knowledge should the competent architect, roofer and installer possess?*	Problem identification+answers RQ1-RQ2
		RQ2	*When and how should this knowledge ideally be exchanged within a Collaborative Design Team?*	Development of RQ3 and RQ4 Hypotheses and Measurable Success Criteria
2	**Descriptive Study 1**	**RQ3**	*What factors hindered the success of the Case Study projects?*	Problem is expressed in practice
		RQ4	*What are the necessary key-components of the Technological Design?*	Key-components identification Development of: RQ 5-6-7-8-9
3	**Prescriptive Study** **WS01** *Students workshop*			Pre-Answers to: RQ 5-6-7-8-9 Research Improvements Determine if the setting encourage interaction Determine if Observation Format is suitable
	WS02 *Students workshop*			Development of alternative observation and analysis methods for the effects of use of the (loosely introduced) Morphological Overview Determine the effect of the use of the (loosely introduced) Morphological overview on knowledge exchange
	WS03 *In-company workshop*	**RQ5**	*Were the tasks sufficiently complex to require the collaboration between the practitioners?*	Evaluation of the analyses to determine the complexity of the Design Task; a quick-scan, the Functional Analysis, pre-defined questionnaires
		RQ7	*Did the face-to-face setting provided by the workshop allows collaboration between the practitioners working on the design task?*	Evaluate the use of the developed Quick-scan, the Observation format 2 and Morphological analysis format
	WS04 *Practitioners workshop*	**RQ6**	*Did both types of practitioners succeed in contributing realizations knowledge?*	Evaluate the use of the developed Video Observation Format and the Research Analysis Protocol
		RQ8	*Did loose introduction of the Morphological Overview lead to acceptance of the tool by the practitioners?*	Evaluate the adoption and use of: the Morphological Overview: Quick-scan, Morphological Analysis Format 3 (MAF3) and Pre-defined questionnaires
	WS05 *Practitioners workshop*	**RQ9**	*When used did the Morphological Overview stimulate for the exchange and structuring of knowledge between the practitioners?*	Evaluation of the effect of the use of the Morphological overview Evaluation of the use of: the Video Observation Format (VOF), the Video Interaction Format (VIF) Development and application of the Collaborative Design Workshop lay-out Finalizing of Research improvements
4	**Descriptive Study 2** *Practitioners Workshop*	**Test RQ 5-9**		Answers to: RQ 5-6-7-8-9 Testing the key-components and Research improvements in the Definitive Collaborative Design Verification of the key-components and the analyzing tools: VOF, VIF, MAF3, and Evaluation Formats Evaluation of the Hypotheses and Measurable Success Criteria

Figure 21 DRM-stages with corresponding Research Questions and Goals.

3.3.2 WORKSHOP 02

The location and the two-day format were the same in WS02 as in WS01. Day 1 and Day 2 took place on October 23 and 30 2006, respectively. The participants were also students of the same educational institutions, however in this workshop there were 24 students, which translated to eight teams of three members.

The task was also the same as in WS01, as was the amount of time given to complete the task in each of the sessions. However, there was a significant change in research focus in WS02 derived from the conclusions of WS01, which lead to the following Goals for research improvements set for WS02:

Goal 1: Develop and apply alternative methods of observation and analysis to determine the effects of loose introduction of the Morphological Overview (MO).
Goal 2: Determine the effect of the loose introduction of the MO on the exchange of knowledge.

First the development Goal 1 is described next that of Goal 2.

GOAL 1

As concluded from WS01 the applied observation- and analyzing format should avoid the disturbance of the team during the design process and needs to be consistent in gathering the data for observation and analyzing. Various observation- and analyzing methods were studied. The tool needed had to be a compact format that is suitable for workshop observations. For this practical reason the TTURC Meeting Observation Form developed by Stokols et.al (2003; 2005) was chosen. This format is a variant of the Interaction Process Model (IPA) (Bales 1976) was selected.

The second conclusion from the workshop WS01 was to avoid direct observation of the team members during the design-process. This was solved as follows. Video-recordings were used to observe the Design Task Settings additionally to the use of photographs. The use of the video recordings allowed for information about interaction to be identified and recorded. This data was analyzed by using the meeting format form. This Form is a data-gathering tool designed to identify interactions between different student-types and outcomes on collaboration and allows observers to identify and record several objective meeting elements to associate these with affective tone and energy intensity qualities.

The student observers used in the previous workshop could not be used in WS02, since it was not possible to provide the required training for observers in a reasonable time. Instead, the three members of BS research group studied the method and acted as observers for WS02.

The TTURC Observation Form is applied as pre-defined observation form on which the categories of interactions are recorded. Instances of these interactions can be seen as indicators of communicative episodes that are both relevant to the task that the team is working on in general, and thought to be relevant in most cases to knowledge exchange in particular in the tasks set in the current research. In order to determine if indeed the interactions regarded knowledge exchange, the time of the interactions needs to be recorded and then further analysis needs to be conducted into the interaction by reviewing the video recording of the relevant points of the design session. To aid this process, the observations were divided into 5-minute segments.

WS02 was organized to assess the usefulness of the observation format and to identify potential problems regarding further use in subsequent workshops. The BS researchers' observations are discussed next.

The BS research group found that it proved very difficult to confidently and clearly distinguish between the categories in a context where multidirectional interactions took place between various design team members. This led to a further difficulty, which was trying to correctly record all of the interactions in a timely manner. The BS team all felt that some interactions had been mis-categorised and that some important elements had been left unrecorded due to this difficulty. The influence or 'noise' from the extra social-emotional aspects which had to be observed and analyzed was experienced as the main cause. The greatest difficulty emerged in the notation of the identified interactions in the time-frames of the video recording of the session and the further analysis and determination of their actual nature and relevance to the current research Goals. As a result of the problems experienced in categorizing the interactions correctly and completely, the video analysis proved much more difficult and time consuming than first imagined.

These findings raised serious concerns within the BS research group, since it was accepted that even though the BS research group had studied the method intensively, their ability to successfully apply it was limited. Because of the difficulty of recording and analyzing the interactions and notations it was decided not to use the TTURC format in the subsequent workshop.

GOAL 2

The conclusion for Goal 1 related to Goal 2: the use and application of an alternative observation and analysis method to determine the effect of loose introduction of the MO on the exchange of knowledge. The necessary requirements should be. First, the format should focus on task related aspects of function-types and related sub-solutions. Second, the function-types and sub-solutions should be clearly defined. Third, the format should capture the interaction and contribution of the students in the team.

The lay-out for the WS02 was as follows:

Day 1: The design teams were required to work on the design task without being introduced to the MO.

Day 2: The MO was introduced to the teams and then the teams were required to use the MO to complete the design task.

As mentioned above, the determination of the influence of the Morphological Overview (MO) in WS02 was made on the basis of a comparison of two contrasting sessions: Day 1, in which the teams were asked to complete the task without being introduced to the Morphological Overview (MO), and Day 2, where the MO was introduced and teams were required to use it in completing the design task.

From the perspective of the BS research group, design can be described as a matter of first determining which function-types need to be included in the design and then determine which sub-solutions can be used to realize these function-types. As such, comparing the amount of function-types and sub-solutions provided by the teams in both settings was considered a good indicator of the effect of introducing the tool. The participants of the teams where changed for each specific Design Task Setting. Figure 22 provides the numbers from the teams from both of the settings. Day 1; without Morphological Overview (MO), Day 2; with Morphological Overview (MO).

WS02 TEAMS	F / DAY 1 / MO	F / DAY 2 / NMO	SS / DAY 1 /MO	SS / DAY 2 / NMO
T 1	3	4	10	12
T 2	5	7	12	24
T 3	7	7	19	29
T 4	5	9	21	23
T 5	6	10	12	28
T 6	6	9	13	16
T 7	3	14	9	30
T 8	9	11	28	36
TOTAL / AVERAGE	**5,5**	**8,9**	**15,5**	**24,8**

Figure 22 Comparison used function-types (F) and sub-solutions (SS) in WS 02.

The table above (Figure 22) shows a substantial difference in terms of the number of both function-types and sub-solutions in the two settings. As can be seen, in the setting in which the MO is used, Day 2, the number of function-types and sub-solutions is without exception equal to or greater compared with the session without the MO (NMO).

A second indication can be given by the results of the questionnaires. In using these ratings it should be remarked that there is a clear limitation. For the participating students attending the workshop was part of their curriculum. Thus, the rating they give could be influenced by this fact and by the fact they get study-points. If these facts do play a role, then it is reasonable to expect that the results may be overly positive, if anything. The results for the questionnaire are presented in Figure 23.

WS02 Rate: 1 – 5	Q1 Use of the MO in general	Q2 How important to stimulate the use of MO within study-practice	Q3 Expectation of future use of MO
MBO average	**2,7**	**3,3**	**3,3**
HBO average	**2,8**	**3,3**	**3,1**
TU average	**3,7**	**2,9**	**3,3**
TOTAL	**3,1**	**3,2**	**3,2**

Figure 23 Average outcomes of Pre-defined questionnaires for WS02.

The overall result is that in average for all different students the use of the MO is positive rated. Although the average for MBO and HBO is slightly less compared to university level in using the MO during the design process a clear distinction can be made. This distinction concerns the difference in the use of function-types and sub-solutions to develop a design in reference to the design experience of the students. Students from MBO and HBO did not learn how to design and using methods for that. What is significant about the answers to Q2 is that the MO is rated as important for their studies more positively by students from MBO and HBO compared with TU-students. This could be an indication that the methodical way of working with the MO is more related to the knowledge background of the MBO and HBO and that students of the TU learn to work on a design methodically. All students on average were optimistic in using the MO in their future studies.

The result for Goal 2 is that with these findings of the use and evaluation of the tool, those are early indications of the usefulness of the tool and a justification for its continued use throughout the research.

3.3.2.1 Results to Goals of WS02

Related to the Goals for the first workshop with students, WS01, two main results can be presented. First, that the workshop setting is a suitable setting to encourage interaction. Second: that the developed Observation Format 1 as a Format for observation had shortcomings in its practical use and content.

From these results it was necessary to define the next Goal for the next research improvements in WS02; to develop and apply alternative methods of observation and analysis to determine the effects of the loose introduction of the MO. Related to the loose introduction of the MO the second Goal for WS02 was to determine whether or not the developed Observation Format 1, is a suitable tool for observation and analysis of the workshop sessions.

As alternative method for observation the TTURC Meeting Observation Form was used, but raised problems related to the practical use and aspects of categorization and the focus on interaction and knowledge exchange. Further improvements were needed to be made to the formats of observation and analysis. Related to the second Goal for WS02 it could be observed that there was clear evidence that the MO could play an important Goal in knowledge exchange in a collaborative design setting.

With these results, for a workshop setting applied with students, the next step in the Prescriptive Study could be made with developing the key-components and research interventions in a Workshop Setting for practitioners. From this point onwards, only practitioners took place in the workshops.

3.3.2.2 Overview DRM Stages, the corresponding Research Questions and Goals

In the overview of DRM Stages in Figure 24 the finalized WS02 with students is presented with related Goals and marked in yellow. The next steps will be organized with Workshops for professionals and therefore related to the key-components. This overview is the guide and introduction to WS03, WS04 and WS05.

The Goals of workshops WS03-WS05 were to introduce, develop and apply research improvements related to the key-components; observation, analysis and evaluation formats. The developed formats are used to answer partly the Research Question's (RQ's) related to the key-components (Design Task, Collaborative Design Team, Practice Setting, Morphological Overview). In steps formats as well as answers to RQ's are developed through these WS03-WS05.

These workshop series and related steps are presented as follows. First a short introduction of the context, the lay-out of the Workshop series with an overview of the Goals and related RQ's for the workshop series. Thirdly the applied research improvements to reach the Goals and answer the RQ's are presented. Fourth the results are presented consisting of the pre-answers to the RQ's. The final part consists of the results for the applied research improvements, implications related to the next step; the next Workshop series.

	DRM Stage	Research Question(s)		Goals
1	**Research Clarification**	**RQ1**	*What type of knowledge should the competent architect, roofer and installer possess?*	Problem identification+answers RQ1-RQ2
		RQ2	*When and how should this knowledge ideally be exchanged within a Collaborative Design Team?*	Development of RQ3 and RQ4 Hypotheses and Measurable Success Criteria
2	**Descriptive Study 1**	**RQ3**	*What factors hindered the success of the Case Study projects?*	Problem is expressed in practice
		RQ4	*What are the necessary key-components of the Technological Design?*	Key-components identification Development of: RQ 5-6-7-8-9
3	**Prescriptive Study**			Pre-Answers to: RQ 5-6-7-8-9 Research Improvements
	WS01 *Students workshop*			Determine if the setting encourage interaction Determine if Observation Format is suitable
	WS02 *Students workshop*			Development of alternative observation and analysis methods for the effects of use of the (loosely introduced) Morphological Overview Determine the effect of the use of the (loosely introduced) Morphological overview on knowledge exchange
	WS03 *In-company workshop*	**RQ5**	*Were the tasks sufficiently complex to require the collaboration between the practitioners?*	Evaluation of the analyses to determine the complexity of the Design Task; a quick-scan, the Functional Analysis, pre-defined questionnaires
		RQ7	*Did the face-to-face setting provided by the workshop allows collaboration between the practitioners working on the design task?*	Evaluate the use of the developed Quick-scan, the Observation format 2 and Morphological analysis format
	WS04 *Practitioners workshop*	**RQ6**	*Did both types of practitioners succeed in contributing realizations knowledge?*	Evaluate the use of the developed Video Observation Format and the Research Analysis Protocol
		RQ8	*Did loose introduction of the Morphological Overview lead to acceptance of the tool by the practitioners?*	Evaluate the adoption and use of: the Morphological Overview: Quick-scan, Morphological Analysis Format 3 (MAF3) and Pre-defined questionnaires
	WS05 *Practitioners workshop*	**RQ9**	*When used did the Morphological Overview stimulate for the exchange and structuring of knowledge between the practitioners?*	Evaluation of the effect of the use of the Morphological overview Evaluation of the use of: the Video Observation Format (VOF), the Video Interaction Format (VIF) Development and application of the Collaborative Design Workshop lay-out Finalizing of Research improvements
4	**Descriptive Study 2** *Practitioners Workshop*	**Test RQ 5-9**		Answers to: RQ 5-6-7-8-9 Testing the key-components and Research improvements in the Definitive Collaborative Design Verification of the key-components and the analyzing tools: VOF, VIF, MAF3, and Evaluation Formats Evaluation of the Hypotheses and Measurable Success Criteria

Figure 24 DRM-stages with corresponding Research Questions and Goals.

The development of the key-components of Collaborative Design Workshop is guided by the Research Questions as presented in the overview of DRM-stages in Figure 24.

In the next Workshop series W03-W04 and W05 the key-components are applied and further developed based on the outcomes of the first two workshops W01 and W02 and the developed observation and analysis formats. Each Workshop Series had a specific focus to one of the key-components and the related Research Questions. In this DRM stage answers to the Research

Questions are further developed to pre-answers. The Goal(s) for this stage are presented as results related to the research improvements.

In the next sections the outcomes, Goals and results of each workshop series WS03, WS04, WS05 are presented consecutively. First WS03 is short introduced about the lay-out and the main Research Question's. Second; the used research improvements are presented; used formats and the modifications of the formats. Third: pre-answer(s) to the Research Question(s). And fourth: results on the research improvements related to the related workshop.

In each Workshop series the focus was on specific Research Questions. Dependent on the results for the development and application of the research improvements to answer the Research Questions the next development for the research improvement has to be applied in the next Workshop series. For the readers' convenience, the key-components of the Collaborative Design Workshop are repeated below, alongside the relevant Research Questions and in which Workshop Series they were developed and applied.

What follows is a brief overview of the Workshop series which were executed in the Prescriptive Study, the key-component(s) developed and applied and the related Research Question(s).

KEY-COMPONENT C1: DESIGN TASK
- Developed and applied in: WS03
- Related Research Question:

RQ5 *Were the tasks sufficiently complex to require collaboration between the practitioners?*

KEY-COMPONENT C2: COLLABORATIVE DESIGN TEAM
- Developed and applied in: WS04
- Related Research Question:

RQ6 *Did both types of practitioners succeed in contributing realization knowledge?*

KEY-COMPONENT C3: PRACTICE SETTING
- Developed and applied in: WS03, WS04, WS05
- Related Research Question:

RQ7 *Did the face-to-face setting provided by the workshop allows collaboration between the practitioners working on the design task?*

KEY-COMPONENT C4: MORPHOLOGICAL OVERVIEW
- Developed and applied in: WS04, WS05
- Related Research Question:

RQ8 *Did loose introduction of the Morphological Overview lead to acceptance of the tool by the practitioners?*

RQ9 *When used, did the Morphological Overview allow the exchange and structuring of knowledge between the practitioners?*

3.3.3 WS03: WORKSHOP SERIES 3

WS03, as mentioned earlier, was a transition between working with the student participants in the pre-test workshops, WS01-WS02, and the first experiments in workshops with practitioners from the professional bodies, WS04-WS05. WS03 was conducted with professional practitioners, but this workshop was conducted within one particular firm, in company.

It is important to point out here that in WS03, while practitioners were used, this workshop took place in-house at one particular company, Brakel Atmos. As such, the practitioners were not screened by the Professional Organizations noted in 3.2.4, as is the case in subsequent workshops.

WS03 was a 1-day workshop that took place at the firm's location in their conference room in June 2007. The 1-day setting was chosen for practical organizational reasons of related to the setting and because of the focus on the design task. There were a total of 9 professional practitioners. Three of the participants functioned as users to serve the firm's wish. The six other participants are practitioners with different educational backgrounds, who were randomly assigned to three teams. So each team consist of one Architect, functioning as designer having object-knowledge, one practitioner, functioning as a Contractor having realization-knowledge, and one user having knowledge about the requirements for the use of the artifact to be designed. Because of the scope of this research project the user knowledge interaction and collaboration is not included here. This implies that the results of only 6 out of 9 practitioners were monitored.

The lay-out for the teams was similar to that of the pre-test workshops: one design-related and two realization-related. The practitioners were split up randomly in 3 teams which consists each of 3 practitioners with different roles within the company. One of the practitioners had the role of the designer (O) and the other two of the Contractors (U and G). The teams were given the same design-tasks. During Task 1 the teams worked without a support tool. For task 2 the Morphological Overview (MO) was loose introduced to teams.

In this Workshop WS03 the focus was on the 'Design Task' and 'Practice Setting', because these are the first requirements for the workshop setting.

Goals for this WS03 were therefore:

1. Evaluate the used views to determine the complexity of the Design Task; a quick-scan, the Functional Analysis and pre-defined questionnaires.

2. Evaluate the use of the quick-scan, the Observation Format 2 and the Morphological Analysis Format to determine interaction in the Practice Setting.

These Goals were organized to answer the Research Questions that relate to these key-components:

RQ 5 Were the tasks sufficiently complex to require the collaboration between the practitioners?

RQ 7 Did the face-to-face setting provided by the workshop format allows collaboration between the practitioners working on the design task?

The commentary on the analysis of WS03 is as follows. First, the applied research improvements are presented related to the Goals of WS03; adaptations made to the main format of observation, Observation Format 2. Next, the Research Questions are addressed in turn, alongside the supplementary methods of analysis. Finally, the results for the Goals are presented; evaluation of the applied research improvements used to observe the workshops and analyze the results are reflected upon in order to determine what changes, if any, need to be made for the subsequent workshops.

3.3.3.1 Application of research improvements: modifications for formats of observation and analysis Observation Format 2

There were two main results with the use of the Observation Formats used in the pre-test workshops. First, while the format did allow the observers to capture and record communication, the picture provided was far too general since the nature of the communication was not clearly described. The results, therefore, were not informative enough in terms of task related knowledge, or in other words function-types and sub-solutions and corresponding realization knowledge. The second result was that in the first version of the Observation Format circles were used to depict communicative interaction between the practitioners. However, what was not recorded was the direction of communication. Thus, an important adaptation was the inclusion of arrows to indicate which participant was communicating with which other participant(s).

In this particular workshop the observations were conducted by Master-students who were trained in the use of the format as part of the 'Design Methodology' course given at the TU/e. One student per team observed 'individual communication', communication patterns and use of morphological charts. An example of the Observation Format 2 observation sheet is provided below (Figure 25.1):

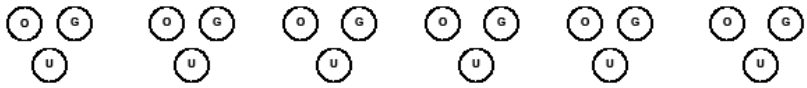
Observation Format 2

Workshops Brakel Atmos / deel 1 / Monitoring Formulier d.d. 21 mei 2007

1. Exchange of functions (Ov) or design sub-solutions / solutions (Oi)

	0-5 minutes	5-10 minutes	10-15 minutes	15-20 minutes	20-25 minutes	25-30 minutes
Designer (O)						
User (G)						
Contractor (U)						

2. Pattern of action



3. Additional

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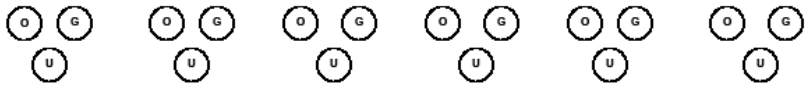
1. Exchange of functions / aspects (Ov) or design sub-solutions / solutions (Oi)

	30-35 minutes	35-40 minutes	40-45 minutes	45-50 minutes	50-55 minutes	55-60 minutes
Designer (O)						
User (G)						
Contractor (U)						

2. Pattern of action



3. Additional

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WS03-Monitoring Format-english Page 1 of 1

Figure 25.1 Modified Observation Interaction Format 2 as used during WS03.

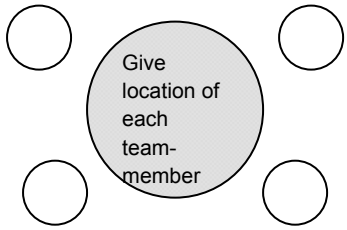
In addition to the above observation sheet, each observer was given the following instructions for its use (Figure 25.1 and Figure 25.2):

INTERACTION FORMAT 2. FOR DESIGN ACTIVITIES WITHIN A DESIGN TEAM: WS03

General items

Name monitor:

Number design-team:



Overview of practitioners on the table:

O = Designer

U = User

G = Contractor

OBS = Monitor

Using the Interaction Format 2.

The overview can be used to gain insight into the two different aspects related to the exchange of knowledge in the design team.

WHAT:

2. *Which discipline / participant introduces an aspect / function (e.g. construction, safety, maintenance) and towards which other discipline(s) / participant(s) within the team (**F**)*
3. *Which discipline / participant makes a **design-related** design-proposal (function, sub-solution, solution; e.g. type of Construction, type of safety-precautions, Photo-voltaic panels), to which other discipline(s) within the team (**O**)*

HOW:

3. *Monitor and notate with an X, in time-frames of 5 minutes, who introduces a function (**F**) – use an X; or a design-proposal (**O**) – use an o*
4. *Notate, in time-frames of 5 minutes, who of the practitioners is most active with which of the other team-members – use an* ➡
5. *Make a photograph, each 5 minutes, of the produced drawings and morphological overviews – for each team*

Additional Instruction:

1. *Make, if necessary, extra notes in relationship to interaction / collaboration within the team*

Figure 25.2 Interaction Format 2 used for WS03.

In order to improve the comparability of results from the different observers, extra methodological steps were taken after the workshops had finished. The observers were asked to further inform their findings by referring to the video recordings and photographs that were taken during the workshops. All of this information was then transferred into a Morphological Analysis Format for each observed team.

Photographs

Each 10 minutes a photograph was taken from the produced documents of the different design teams; the photographs were coded afterwards related to Workshop-number (WS0n), Design Task Setting (Tn), Team-number (An) and number of photograph (n). Photographs were taken by assistants.(Figure 28)

Video-recordings

Due to practical organization problems there were only 3 cameras available. Because of the size of the conference-room and the position of the different teams the sound-quality was rather poor. For the next workshop the space between the different teams was enlarged and position of microphones improved. Video-tapes had to be converted to digital-format. Video-tapes were coded with stickers;

Workshop-number (WSn), Design Task Setting (Tn), Team-number (An). Video-preparing as well as video-recordings were done by assistants.

Morphological Analysis Format

The structure of the Morphological Overview has not only the possibility to be used as a structuring tool for design it was also used as one of the formats to structure and analyze the data from the observations during the different workshop-settings. To determine the function-types a first reference list was used from the expected function-types related to the design task. For this reference list the available information at that time was used from the Professional Organizations. The used competence profiles for WS03 were preliminary versions. Per Design Task Setting the different sub-solutions are notated in the empty boxes, corresponding to related function-types. The design-team coding (e.g. An = individual design task, Bn = team design task 1, or Cn = team design task 2) is added between brackets in the same box as the sub-solution. In this way per Design Task Setting in a structured way one overview can show the amount and type of function-types and related sub-solutions notated by the teams for one design-task in a highly structured way.

A fragment of the Morphological Analysis Format with this function-type reference list is shown in Figure 26 This reference-list is organized with in total 19 function-types in total of which 8 are realization-related (in the green box of Figure 26) and 11 object-related function-types (in the yellow box of Figure 26).

WS03 Task Team: Functionalities / Sub-solutions		
Rain / water proof		
Temperature / protection		
Ventilation		
Heating & Cooling		
Energy generation		
Maintenance		
Safety		
Construct & Build		
Fire-resistant		
Light / sun + protection		
Functions for the building		
Architecture		
Shape / form		
Construction		
Building Physics		
Costs / finance / benefit		
Utilities		
Material		
Climate		
Total F=		

Figure 26 Morphological Analysis Format with reference-list 1 for the function-types (19 function-types).

3.3.3.2 Pre-answers to Research Questions for WS03

The first Research Question to be answered is:

RQ5 *Were the tasks sufficiently complex to require collaboration between the practitioners?*

In WSO3 the professional teams were given design tasks that were representative of what such practitioners may face in the real world. In this workshop an existing building that had been recently renovated was chosen. This building is the National British Museum in London, which was built by Sir Robert Smirke in the 19th century and was remodeled by Architect Sir Norman Foster in 2000 through the addition of a new courtyard and new space-frame roof (Figure 27).

The teams were given an instruction with photographs of the object:
Design a new roof, as an alternative to the roof of Foster for the courtyard and for the public functions of the museum

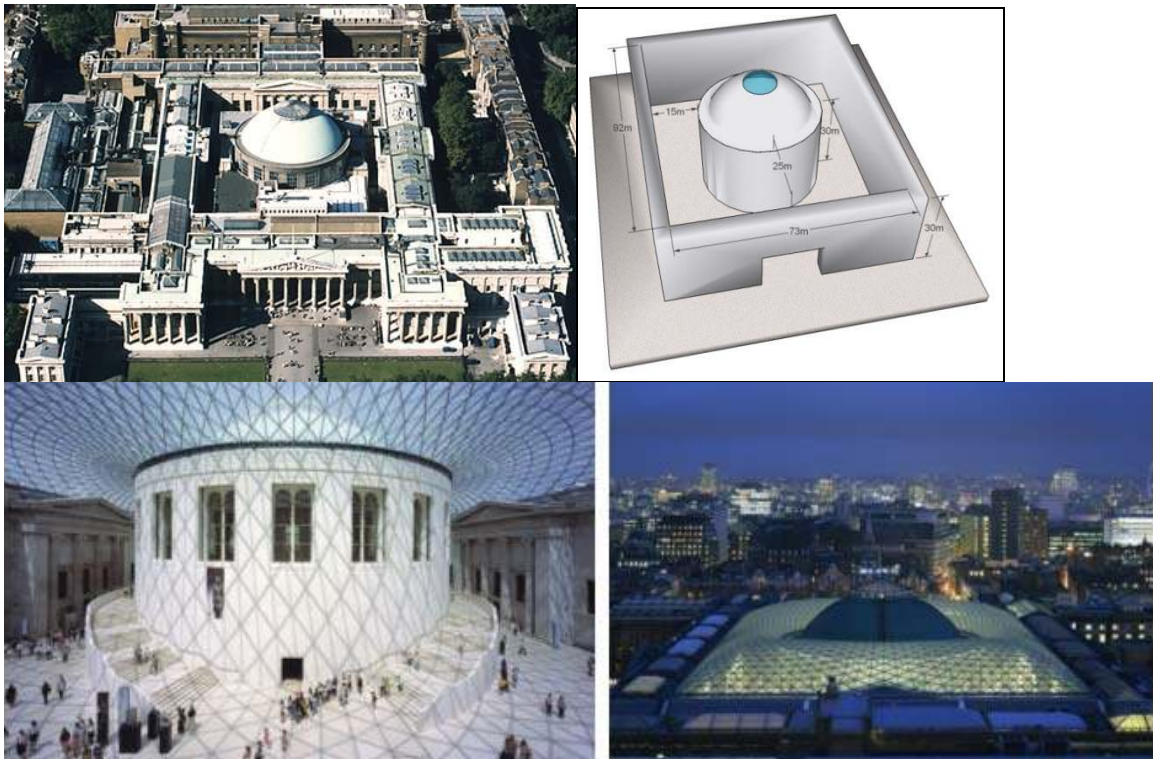


Figure 27 Photographs from the design task situation: National British Museum, with new courtyard and space-roof by Sir. N. Foster.

The lay-out for WS03 was as follows. The day started with an introduction of the task for individual use, in order to get acquainted to the design task, especially for the Contractors. The second step was the same design task for a team without the use of the Morphological Overview (MO). The third step was with the same design-task but with changed teams and with loose introduction of the MO. The teams were not forced to use the tool. The focus within the workshop was not on the use of the MO but on the design task and the face-to-face setting. The results of RQ5 are discussed in turn below, followed by the results of RQ7.

In order to find answers for RQ5, the produced documents by the teams were examined together with the photographs of the design teams, which were taken every ten minutes. The determination whether the task was complex enough was done in three different analyses.

Analysis 1. A quick scan was made of all produced documents of the different teams to get a first impression of the variety of used type of documentation and used function-types. Figure 28 gives an impression of two representative teams within WS03, using different types of communication like sketches with schemas, plans and details or with words in the Morphological Overview. Even from this initial impression it is possible to identify how the teams were working on the design-tasks.

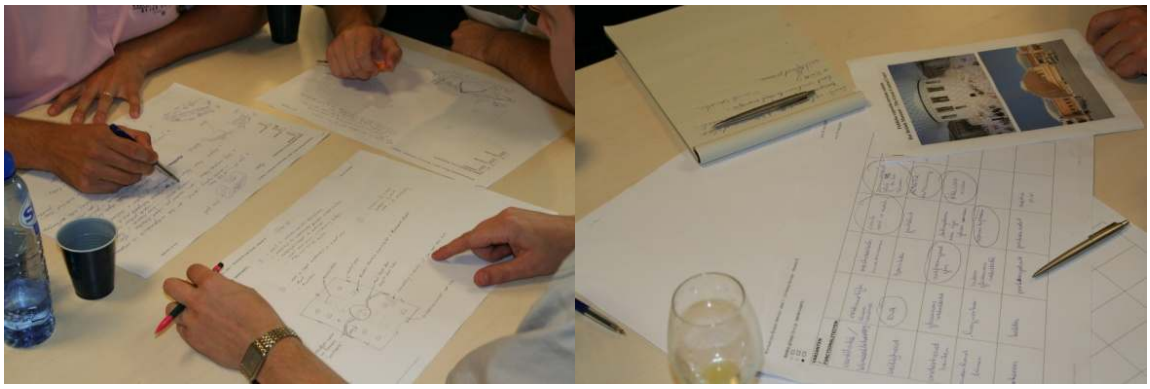


Figure 28 WS03 shows working within teams with different types of media by different practitioners.

Analysis 2. The produced documents are examined for the Functional Analysis. An indication of the complexity is the variety of notated function-types within the different teams. The collected function-types by the use from the documents are organized in a Morphological Analysis Format. Figure 29 shows the Morphological Analysis Format for Task 1 (MAF1), for teams B1, B2 and B3 (without Morphological Overview). Figure 30 shows the Morphological Analysis Format for Task 2, for teams C1, C2 and C3 (with Morphological Overview). In Figures 29 and 30 in the vertical column left the reference function-types are presented and on the horizontal axis the related sub-solutions; between brackets the corresponding teams which notated the items. In the green box: realization-knowledge function-types.

WS03 Task 1 / NMO Team: B1, B2, B3 FUNCTION-TYPES (F) / SUB-SOLUTIONS (SS)								TOTAL SUB-SOLUTIONS (SS)
Rain / water proof	Ring-system internal (B1)							1
Temperature / protection								
Ventilation	Mechanical Ventilation (B1)							1
Heating & Cooling	Smoke / heat tubes (B2)							1
Energy generate								
Maintenance	Servicing-bridge (B1, B3)	Maintenance system installations (B3)						2
Safety	Emergency routing (B2, B3)	Safety-guarding alarm (B2)	Anchor system (B3)	Certification of items (B3)				4
Construct & Build	Building crane routing (B3)							1
SUB-TOTAL REALIZATION F = 6								SUB-TOTAL REALIZATION SS = 10
Fire-resistant	Compartments (B1)	Smoke-heat-outlet (B1, B3)	Sprinkler (B1, B2)	Detection-system (B1)	Gas-powder blush system (B3)	Evacuation routing from roof (B3)		6
Light / sun + protection	Sky-cupolas (B2)	Sun-reflecting roof-canopy (B2)						2
Functions for the building	Restaurant / bar (B2)	Storage art (B2)	Parking garage (B2)					3
Architecture	Has to be beautiful (B2)							1
Shape / form	Pyramid (B1)	Double bent (B3)						2
Construction	Steel construction-open frame (B3)							1
Building Physics								
Costs / finance / benefit	Cost-management on budget (B2)							1
Utilities	Sanitary equipment (B2)	Elevators / stairs to roof (B2)						2
Material	Steel (B3)	Glass (B3)						2
Climate	Computer-system (B3)							1
SUB-TOTAL OBJECT F = 6								SUB-TOTAL OBJECT SS = 21
TOTAL FUNCTION-TYPES F =16								TOTAL SUB-SOLUTIONS SS = 31

Figure 29 Morphological Analysis Format 1, WS03, Task 1.

WS03 Task 2 / MO Team: C1, C2, C3 FUNCTION-TYPES (F) / SUB-SOLUTIONS (SS)								TOTAL SUB-SOLUTIONS (SS)
Rain / water proof								
Temperature / protection								
Ventilation	Natural ventilation (C1, C2, C3)	Mechanical Ventilation (C1, C2, C3)	Airco-system (C1)	Sun-protection glass (C1, C2)	Air-evaporation-system (C1)	Combination natural / mechanical ventilation (C3)		6
Heating & Cooling								
Energy generate								
Maintenance	Servicing-bridge (C2, C3)	Hydraulic hoist (C2, C3)	Cleaning robot (C2)	Self cleaning glass (C2, C3)	Telescope crane (C3)	Anchor-system (C3)		6
Safety	Emergency routing (C1, C2)	Safety-guarding alarm (C1)	Hydraulic hoist (C2)	Anchor system (C3)	Evacuation installation (C1, C3)	Organizing / training staff (C1)	Scaffolding system (C2)	7
Construct & Build	Logistics for access roof (C1)	Risk analysis (C1)	Rod-system (C2)	Spider-system (C2)	3-D Structure (C2)	Prefab-system with crane (C2)		6
SUB-TOTAL REALIZATION F = 4								SUB-TOTAL REALIZATION SS = 25
Fire-resistant	Compartments (C1, C2)	Smoke-heat-outlet (C1, C2, C3)	Sprinkler; dry, water, mist (C1, C2, C3)	Detection-system (C1, C3)	Blush system; Argon, CO2 (C2, C3)	Evacuation routing from roof (C2)	Dry blush-tube system (C2)	7
Light / sun + protection	Blinds (C2)	Sun-reflecting roof-glass (C2, C3)	Printed glass (C3)					3
Functions for the building	Parking garage / facilities (C2, C3)							1
Architecture								
Shape / form	Pyramid (C1)	Bent single (C1)	Pitched single (C1)	Pitched double (C1)	Mansard (C1)			5
Construction	Self baring system (C2)	Columns (C2)						2
Building Physics								
Costs / finance / benefit	Costs of montage (C1)	Risk analysis (C1)						2
Utilities	Emergency room (C1)	Elevators / stairs to roof (C2, C3)						2
Material	Steel (C2)	Glass (C2, C3)	Wood (C2)					3
Climate								
SUB-TOTAL OBJECT F = 8								SUB-TOTAL OBJECT SS = 25
TOTAL FUNCTION-TYPES F =12								TOTAL SUB-SOLUTIONS SS = 50

Figure 30 Morphological Analysis Format 1, WS03, Task 2.

The result of the analysis of Task 1 (Figure 29) shows that 16 out of 19 (84%) different function-types related sub-solutions were notated by the teams and 31. For Task 2 (Figure 30), 12 out of 19 function-types (63%) and 50 related sub-solutions were notated. With this first view it can be stated that a variety of function-types was introduced and notated by the different teams.

Analysis 3. Consists of the results of the pre-defined questionnaires administered directly after and after 6 months. The results are shown for the specific question related to the design-task (Figure 31). In Figure 31, the designers are coded with O and the Contractors with G. The ratings are the average on the scale 1-5 of all participants. The following rating where introduced to the practitioners and the score used for the researcher between brackets , 1: poor (2) , 2: insufficient (4), 3: sufficient (6), 4:

good (8) and 5: very good (10). A total overview of all questions is given in the Appendix 13 (Figure 13.1, page 190).

WS 03	**Q3**
Rating: 1-5	How did you experience the complexity of the design task
WS03 – Designers (O) average direct / 3 out of 3 / 100%	2,7
WS03 – Designers (O) average after 6 months / 3 out of 3 / 100%	2,6
WS03 – Contractors (G) average direct / 3 out of 3 / 100%	3,3
WS03 – Contractors (G) average after 6 months / 2out of 3 / 66,6%	3,5

Figure 31 Average outcome Questionnaire (fragment) WS 03 on complexity task.

The pre-defined questionnaire is used in two ways. The first questionnaire is used directly after the workshop and the second after 6 months. The answers show that the designers experienced the design tasks as less complex design task. Directly after the workshop the difference between the rating of designers and Contractors is 0,6 and after 6 months this is 0,9. This might be explained by the difference in background and experience. On the basis of these 3 views, a consistent picture of the results regarding the complexity of the design task has emerged. So the following pre-test answer can be formulated for Research Question 5:

> The results show that the design-task was complex enough for the different practitioners to require collaboration between the practitioners, thus the type of task will be adopted for the next workshop setting. The format to determine the task complexity will be applied for the test in the Descriptive Study 2.

The next step in the analysis of the Practice Setting is to determine whether the face-to-face setting is a positive setting for collaboration, as stated in RQ7

RQ7 *Did the face-to-face setting provided by the workshop allows collaboration between the practitioners working on the design task?*

Determining whether the face-to-face setting stimulates collaboration is done by using the following analyses.

Analysis 1. A quick scan of the photographs of the different teams in the different design-task sessions. Viewing the different photographs and the video-recordings give a good first impression if the face-to-face setting allowed the practitioners to collaborate on the design task. During the different sessions there is visible collaboration between all practitioners within the different teams. Photographs from Figure 32 show examples of these collaborative situations during the design-process; what can be viewed is a discussion between the different practitioners by pointing out aspects on the produced documents with each other.

Result of analysis 1 in WS03 for both Task 1 and Task 2 is as follows. In Task 1, without the use of the Morphological Overview interaction was identified in all teams, but it was predominantly identified in speech and notations on paper, rather than in design sketches

Figure 32 WS03; teams working together on the design task with different working formats; using Morphological Overview as well as sketches.

Analysis 2 determines the different types of communication-types (speech, sketches, MO) between the practitioners during the design process. To confirm that the notated object- and realization-related function-types and sub-solutions are contributed by the different practitioners in a team an additional step was necessary. Therefore the Observation Format 2 was used during the design-task sessions.

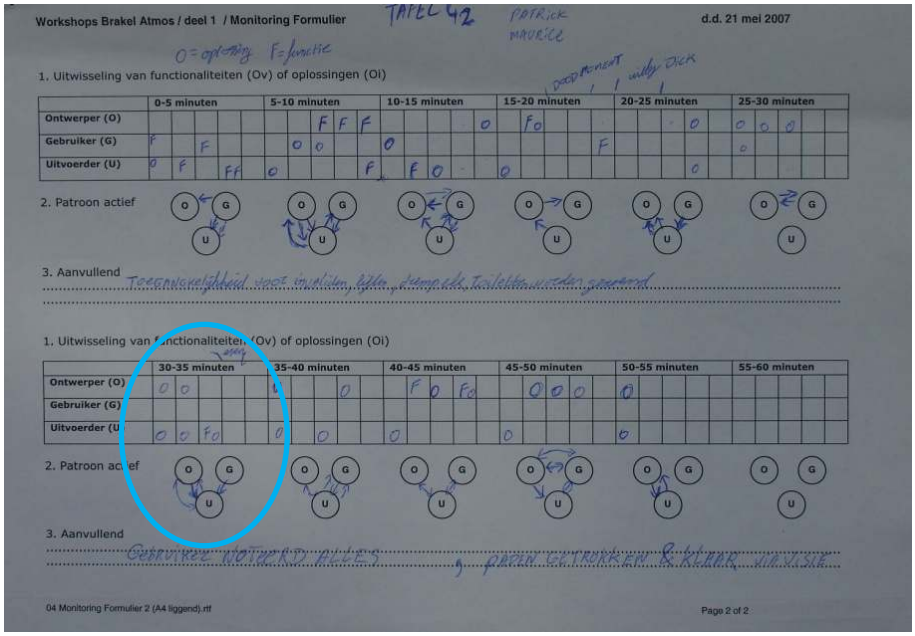


Figure 33 Example of used Observation Format 2 for WS03.

Figure 33 gives an example of the Observation Format 2 which is used in WS03. The used coding is in blue; F for used function-types and O for used solutions related to the design task; arrows represents the direction of collaboration between the three practitioners; O represents the designer in the team, G represents Contractor C1, U represents Contractor C2. The blue circle shows the time-frame where the example of Figure 31; interaction between Designer (D) and Contractor 2 (U) about design-solution (O) and function (F).

By using the notated arrows for each time-frame of 5 minutes an indication could be given of the interaction between the different practitioners related to function-types (F) and solutions (O). Another

indication of the interaction could be traced by using the photographs, each 10 minutes, and video-recordings in combination with the Observation Format 2. Confirmation of the interaction is indicated by Figure 34.

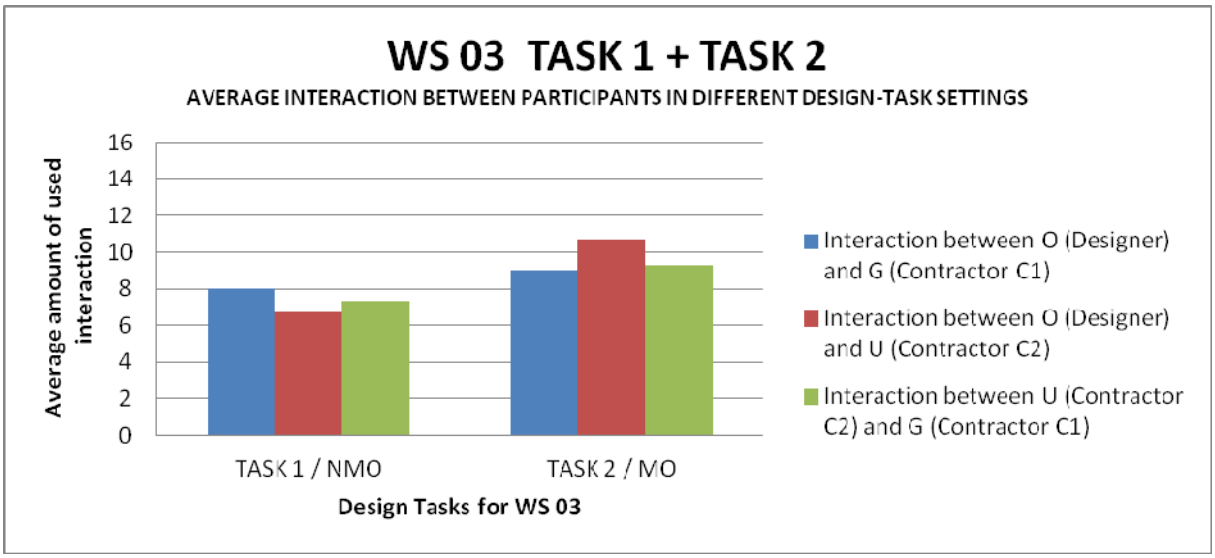


Figure 34 WS 03 Results for Task 1 and Task 2 (x axis) using Interaction Format.

On the y-axis the average amount of communication-activities is shown. On the x-axis the different interaction situations are grouped for the different practitioners of one team. The left group is related to Task 1, the right group are the results for Task 2. What can be observed is an equal interaction level between the different practitioners in the different teams and Design Task Setting. In the Design Task Setting Morphological Overview (MO) there is a tendency towards more interaction between the practitioners in both days than in the Design Task Setting without the use of the MO (NMO). Related to the introduction of the MO in design-task MO this gives an indication that introducing the tool did not decrease interaction, which in turn indicates the positive influence that should be confirmed in the subsequent workshops.

In analysis 3 the different notated function-types are determined by the use the produced documents and photographs which are organized in the Morphological Analysis Format (MAF). Another indication of collaboration used is the function-types and related sub-solutions notated by the teams. The first impression for the WS03 was gained, related to RQ 5, with the use of the produced and photographed documents of the different teams. Figures 35 and 36 show examples of these documents within WS03.

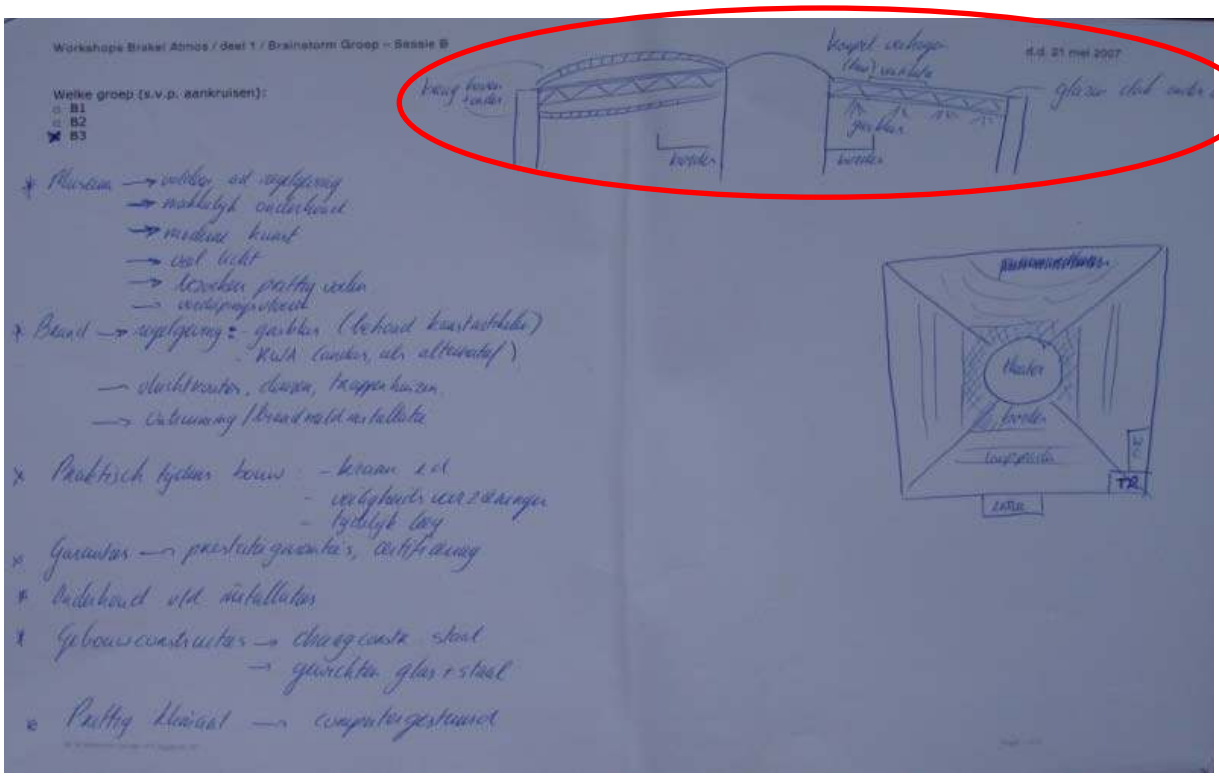


Figure 35 Photograph document Task 1, Team B3, Time-frame 30-35 minutes.

Figure 35 shows one of the produced documents of Team B3. In this document on the left side the following function-types and sub-solutions are notated: Function-types for building and roof, Fire-safety, Built & Construct, Maintenance, Construction and Climate. In the red-circle an example of notated function type 'Maintenance' with sub-solution 'Servicing Bridge'.

Figure 36 Photograph document WS03, Task 2, Time-frame 40-45 minutes.

Figure 36 shows the use of the Morphological Overview (MO) with all produced MO-documents of a team in WS03; within these overviews the following function-types were notated: Fire-safety, Ventilation, Maintenance, Daylight use, Accessibility, Functions for building and roof, Construction and Construct & Build. This Figure is the example where all participants first made their own MO, then discussed them and finally made one team overview with the agreed function-types and sub-solutions for the design (on the bottom of Figure 36). Both examples show the notation of object- and realization knowledge.

These two examples, one from Task 1 and the other of Task 2 are representative for WS03. With the Morphological Analysis Format (MAF) the variety of object- and realization-knowledge for all teams in

one Design Task Setting can be organized. The corresponding MAF's are in Figures 29, & 30 (page 92). Figure 37 gives an overview of the percentage of determined object- and realization-related function-types and sub-solutions for WS 03 with all teams. The table shows the percentage of the total notated function-types and sub-solutions for Design Task Setting Task 1 (Teams B1, B2 and B3) and Task 2 (Teams C1, C2, C3).

Figure 37 shows the contributions of the teams related to the reference-list of function-types (19 function-types); if all function-types of the reference list are notated this means 100% of the object- and realization function-types are notated. Thus, if not all function-types from the reference list are notated the total percentage of object- and realization-knowledge will be less than 100%. For object-related function-types total of 11 is 100%, for realization-related function-types total of 8 is 100%. Next to the function-types, the table presents the percentage of notated sub-solutions in the teams. For the sub-solutions there is no strict reference, here all notated sub-solutions of all teams within a design-task is 100%. From all notated sub-solutions in a specific design-task the percentage of object- and realization sub-solutions are presented.

WS03 KNOWLEDGE TYPE	**SOLUTION-TYPES**	**TASK 1 / NMO** **B1, B2, B3**	**TASK 2 / MO** **C1, C2, C3**
OBJECT (11)	FUNCTION-TYPES (F)	(10) 91%	(8) 73%
	SUB-SOLUTIONS (SS)	10 (32%)	25 (50%)
REALIZATION (8)	FUNCTION-TYPES (F)	(6) 75%	(4) 50%
	SUB-SOLUTIONS (SS)	21 (68%)	25 (50%)
TOTAL F		84%	63%

Figure 37 WS03: overview of notated object and realization-related function-types and sub-solutions.

The result of analysis 3 is that for both design-task 1 and 2 a balanced variety of object-related and realization-related function-types and sub-solutions is notated. This is the second indication that the setting allows collaboration.

Comparing the 3 analyses, the same results are shown: there is collaboration in the different design-teams and in the different Design Task Settings. With this conclusion we can answer RQ7

A few remarks have to be made for the results and the use of the developed Observation Format 2. Although the Observation Format 2 worked better in practice compared to Observation Fomat 1 and the TTURC Meeting Observation Form, three characteristics of the format need to be improved. First, the Observation Format 2 is used during the live design-process and is therefore experienced as a disturbing and influencing factor on the team. Second, the structure and content of the Format 2 is not defined and fine grained enough to determine the contributions of the practitioners within the teams. Observation should focus on interaction and knowledge exchange related to used function-types and sub-solutions of the practitioners. The third remark is related to the use of the format for analysis. A clear reference list for the function-types is needed. Organization of the communication activities of the practitioners in the format has to be developed for an interrelated overview between team-members, type of communication activity, type of function and sub-solution and time-frame.

Although with the developed format the interaction and partly the type of communicated function-types and sub-solutions related with the team-members could be determined, the results are not fine-grained enough to state the answer of the RQ7 definitively, so this answer is a pre-test answer:

> The results for WS03 show that the face-to-face setting allows the different practitioners to collaborate by interaction and knowledge exchange, however the observation and analyzing format to determine the collaboration needs improvements to organize a more precise analysis for the different types of interaction.

Reflecting on the answers on Research Question 5 and 7 it can be concluded that for the Collaborative Design Workshop, stimulating interaction and knowledge exchange in small teams, complexity of a design task is required in a face-to-face setting. To confirm the collaboration for their various types of interaction and types of tasks, further investigation is necessary. The relevance of the type of task will be confirmed or denied in the next workshop experiment and the tests in Descriptive Study 2.

Based on the observations during the workshops and analysis of the documentation generated by the teams the practice Setting of the workshop and the level of complexity of the Design Task showed to stimulate interaction substantially (between 10% for O interaction G and 30% for O interaction with U; see Figure 34, page 95) and meaningful collaboration in the design teams. The complexity of the Design Task could be verified and was used in the next workshops with additional Design Tasks

3.3.3.3 Results for the research improvements for Goals of WS03

Collaboration withing Design Teams is necessary to work on complex tasks. To determine whether the Design Tasks selected and used in the WS03 were complex enough, three different analyses were used; a quick-scan, the use of Functional Analysis and pre-defined questionnaires. The evaluation of these views as first Goal for this WS03 was that by using these three different perspectives were sufficient to determine the complexity of the Design Tasks. These three analyses could therefore be used as finalized research improvements related to the key-component Design Task.

Related to the key-component Practice Setting the following analyses and related methods were used: the quick-scan, the Observation Format 2 and the Morphological Analysis Format (MAF). Evaluation as the second Goal of this WS03 focuses on the Observation Format 2 and the MAF. To determine interaction with the Practice Setting modifications were made to the Observation Format 2 in order to make it more suitable to use for observation, it became evident during the analysis stage that further refining was required. The main issues with the Observation Format 2 were that it did not allow for sufficiently precise recording of the interactions that took place. Further precision was considered crucial In order to provide a detailed enough analysis of the data to answer Research Questions RQ6 and RQ9 in subsequent workshops. In order to do this, the next step for an Observation Format needed also to provide mechanisms to record the following information: 1) *who* is sender and who is receiver (Architect, Contractor); 2) *what* was sent or received (type of function-types and sub-solutions); 3) *how* was it sent / notated (speech, sketch, MO); 4) *when* was it sent / received / notated (more specific time frames).

The use of the MAF was efficient to structure and analyse the explicitly notated function-types and sub-solutions by the different teams. This format therefore could be used as finalized research improvement related to RQ7. A more effective and useful format to organize and structure the interaction between the practitioners in the Design Teams had to be developed.

Because in practice a Collaborative Team consists of practitioners from different companies, the next step should be to develop and apply the Practice Setting related to its functioning with practitioners from different disciplines who could apply freely for the workshop.

3.3.3.4 Overview DRM Stages, the corresponding Research Questions and Goals

The status of the research project with finalizing WS03 and corresponding Research Questions and Goals is presented in the overview of the DRM Stages in Figure 38. From the results of WS03 the Goals and Research Questions for the next step in the research project can be taken in WS04.

	DRM Stage	Research Question(s)		Goals
1	**Research Clarification**	**RQ1**	*What type of knowledge should the competent architect, roofer and installer possess?*	Problem identification+answers RQ1-RQ2
		RQ2	*When and how should this knowledge ideally be exchanged within a Collaborative Design Team?*	Development of RQ3 and RQ4 Hypotheses and Measurable Success Criteria
2	**Descriptive Study 1**	**RQ3**	*What factors hindered the success of the Case Study projects?*	Problem is expressed in practice
		RQ4	*What are the necessary key-components of the Technological Design?*	Key-components identification Development of: RQ 5-6-7-8-9
3	**Prescriptive Study**			Pre-Answers to: RQ 5-6-7-8-9 Research Improvements
	WS01 *Students workshop*			Determine if the setting encourage interaction Determine if Observation Format is suitable
	WS02 *Students workshop*			Development of alternative observation and analysis methods for the effects of use of the (loosely introduced) Morphological Overview Determine the effect of the use of the (loosely introduced) Morphological overview on knowledge exchange
	WS03 *In-company workshop*	**RQ5**	*Were the tasks sufficiently complex to require the collaboration between the practitioners?*	Evaluation of the analyses to determine the complexity of the Design Task; a quick-scan, the Functional Analysis, pre-defined questionnaires
		RQ7	*Did the face-to-face setting provided by the workshop allows collaboration between the practitioners working on the design task?*	Evaluate the use of the developed Quick-scan, the Observation format 2 and Morphological analysis format
	WS04 *Practitioners workshop*	**RQ6**	*Did both types of practitioners succeed in contributing realizations knowledge?*	Evaluate the use of the developed Video Observation Format and the Research Analysis Protocol
		RQ8	*Did loose introduction of the Morphological Overview lead to acceptance of the tool by the practitioners?*	Evaluate the adoption and use of: the Morphological Overview: Quick-scan, Morphological Analysis Format 3 (MAF3) and Pre-defined questionnaires
	WS05 *Practitioners workshop*	**RQ9**	*When used did the Morphological Overview stimulate for the exchange and structuring of knowledge between the practitioners?*	Evaluation of the effect of the use of the Morphological overview Evaluation of the use of: the Video Observation Format (VOF), the Video Interaction Format (VIF) Development and application of the Collaborative Design Workshop lay-out Finalizing of Research improvements
4	**Descriptive Study 2** *Practitioners Workshop*	**Test RQ 5-9**		Answers to: RQ 5-6-7-8-9 Testing the key-components and Research improvements in the Definitive Collaborative Design Verification of the key-components and the analyzing tools: VOF, VIF, MAF3, and Evaluation Formats Evaluation of the Hypotheses and Measurable Success Criteria

Figure 38 DRM-stages with corresponding Research Questions and Goals.

3.3.4 WS04: WORKSHOP SERIES 4

The workshop series 4 (WS04) took place in a conference room at end of September 2007 and comprised a one-day workshop in which two separate tasks needed to be executed. Eleven practitioners applied for the workshop. This uneven number of participants led to 5 teams in total, four of which comprised of one Architect and one Contractor, and the remaining team consisted of 1 Architect and two Contractors.

The focus of WS04 was on the key-components 'Design Support Tool' and the 'Design Team'.

Two of the 9 Research Questions are addressed for the analysis of these workshop series, RQ6 and RQ8.

RQ6: Did both practitioners succeed in contributing realization knowledge?

RQ8: Did loose introduction of the Morphological Overview lead to acceptance of the tool by the practitioners?

To answer these Research Questions the following Goals were set for WS04:

1. Evaluate the teams' adoption and use of the Morphological Overview; use of quick-scan, the Morphological Analysis Format 3 and pre-defined questionnaires

2. Evaluate the use of the Video Observation Format and the Research Analysis Protocol to determine the contributed knowledge, with the focus on the realization knowledge, by the different practitioners.

The workshop started with a general introduction to the Morphological Overview (MO) and the content of the two tasks. The first task required individuals to execute design task, while the second task required collaboration between both participants: an Architect and a Contractor. In both cases the MO is introduced and loosely prescribed. In practice this means that the teams were free to use the tool or not.

The purpose of introduction of the Morphological Overview (MO) as a Design Support Tool in WS04 was to help the practitioners to interact and exchange the knowledge of each other related to the design task. Therefore it was important to determine how the multidisciplinary design teams with different educational backgrounds would react to the introduction of the MO. Previous research from Savanović (2009) argued that firm prescription of a Design Support Tool may lead to its rejection by the teams. One reason for this rejection could be that the practitioners may experience test anxiety when they are forced to use a new tool, and as such they may not put their best foot forward. For this reason, WS04 contained two application conditions. The first application condition was: the MO is introduced and individual practitioners are given the option to use it if they wish. The second condition concerns the team: practitioners were asked to work in teams from the outset, again with the same freedom to use the MO or not. The research interest was to determine how many teams used the MO through free choice. Setting 1 was used as a learning cycle for all practitioners. Since half of the practitioners, the Contractors, were not expected to possess much object knowledge compared to Architects, the final designs that were produced would not provide any real insight. Thus, the discussion of the results in this section is based on the results of the second setting.

To provide an answer to RQ6 which could give insight in the individual contributions within the CD teams, as research intervention further improvements were made to the formats of observation and analysis. The improvements are described below.

3.3.4.1 Application of the research improvements: observation formats and analysis format

The use of video recording was substantially improved for the observations in WS04. In order to avoid issues with audibility noted in the previos workshop, the teams were positioned much further apart on a separate working desk and additionally professional microphones were used to record the speaking. The observations were done through video-camera focusing on desk + microphone on desk; photographs of produced items each 10 minutes; loose observation by researchers (Figure 39).

Once the workshop had finished, the video-tapes were converted to digital-format and coded with stickers; Workshop-number (WSn), Design Task Setting (Tn), Team-number (An). Video-preparing as well as video-recordings were done by assistants / students. The use of photographs each ten minutes was retained throughout the research, as the photgraphs provided an interesting record of the development of each teams' progress on the design task.

The main motivation for using video recording for the observation was to get an exact and clear 'picture' or impression of the interaction that takes place. The previously used Observation Format did not provide a clear enough picture of the recorded interactions. First, the Observation Format did not provide a clear distinction between object knowledge and realization knowledge. Second, it did not distinguish function-type (f*n*) and sub-solution (ss*n*), and third: it did not provide an easy format to record which participant sent the knowledge and whether or not the recipient responded or acted upon it. In addition, the close proximity of the human observers was sometimes noted as obtrusive by the design teams.

In response to these improvements of the observation format, two new analyzing formats were developed; the Video Observation Format and the Morphological Analysis Format. Each format will be described below in detail.

Figure 39 Example of collaborative team in WS04.

Video Observation Format

A specific Video Observation Format (VOF) is applied at this stage of the research. This format needs to provide a comprehensive and user-friendly observation that does not affect or hinder the workshop participants in executing their tasks. The VOF is used after the execution of the workshop to guide the review and analysis of the video recordings of the participants in the design teams. A fragment of this Video Observation Format is provided below in Figure 40, followed by an explanation of the coding used.

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Functionalities / Sub-solutions WS: Team: Task: Time part: 1-10 min.	Participant	Used	How		T 1 – 2 minutes	T 3 – 4 mi
a. Rain / water proof b. Temperature proof c. Ventilation d. Heating & Cooling e. Sustainable energy generation f. Maintenance g. Safety h. Construct & Build j. Fire resistance k. Light & sun protection / use l. Functions building / roof m. Architecture n. Shape o. Construction p. Building Physics q. Costs / finance / benefit r. Utilities s. Material s. Climate	ARCHITECT	only as function	speech / talking			
			on paper	1; sketch		
				2; MO		
		related to design > combination	speech / talking			
			on paper	1; sketch		
				2; MO		
		related to design > new	speech / talking			
			on paper	1; sketch		
				2; MO		
	CONTRACTOR	only as function	speech / talking			
			on paper	1; sketch		
				2; MO		
		related to design > combination	speech / talking			
			on paper	1; sketch		
				2; MO		
		related to design > new	speech / talking			
			on paper	1; sketch		
				2; MO		

Figure 40 Fragment of the used Video Observation Format.

As Figure 40 shows The VOF is structured in four main columns. The first column on the left records and applies an alphabetized coding to the 19 function-types of the reference list (Figure 26, page 89). In this Design Task, the function-types used were derived from team contributions in WS03. The realization-related function-types are marked within the green box. The sub-solutions relating to function-types are numbered 1-n. Thus, for a given function, e.g. Temperature, the function is coded as B from the list above and the first sub solution contributed would be recorded as B-1, the second as B-2 etc. The symbols at the end of the reference-list (>, < and -) are used at the beginning of each notation of the observations of communicated function-types or sub-solutions between the practitioners. Depending on the situation where these items are sent (>) by the practitioner or received (<), the specific symbol is put in front of the communicated item. When there is no explicit way the symbol neutral is used (-). The second column, named 'participants', makes a clear distinction between the team members as practitioners, I.E. the Architect on the one hand and the Contractor on the other. The third column, 'used', distinguishes between three possible uses of a contributed function from a given participant. The first use depicts the introduction of a task related function type in general. Here, although the function-type is introduced, it does not necessarily become part of the design. The second use depicts the contribution of a function belonging to the reference list alongside the combination of other design contributions. The third use depicts contributions that were not present in the reference list, and as such are classified here as 'new' contributions. The fourth column, 'how', records in what form the contribution was made.

The subsequent columns are used to divide the analysis into manageable time frames of two minutes. Thus, the column entitled T1-2 will be followed by T3-4, which in turn is followed by T5-6 and so on.

Morphological Analysis Format

The second format which is used in this workshop is the Morphological Analysis Format (MAF), adopted from WS03**.** This Format structures all function-types and the related sub-solutions as notated by the participants in the teams according to the design-tasks executed to provide overview on the use and adoption of the MO. The realization-related and object-related function-types are organized on the vertical axis.

For WS04 the same reference-list for function-types was used as in WS03 (Figure 26, page 89).

Research Analysis Protocol

In order to answer RQ 6, a Research Analysis Protocol is applied in the workshop. This protocol is structured as follows. First, all of the design documents completed by the team and the photographs taken of the teams during the sessions are collected and analyzed by using the Morphological Analysis Format 1 (MAF1). The output of this analysis provides an overview of the teams' contributions. Next, the video recordings of the teams need to be reviewed and analyzed by using the VOF. The data from this analysis, the notated function-types and sub-solutions were added to the MAF1 conducted in the first step in MAF2. The end result of this process showed the gathered data of all the team contributions. These data were then used to determine how sufficient the teams' contributions actually were. This determination was made by referring to the function-type reference-list (19 function-types) of expected function-types and sub solutions provided in the VOF. So, the four-step analysis is as follows: Step 1: use of the Morphological Analysis Format 1; step 2: use of the Video Observation Format; step 3: use of the Morphological Analysis Format 2; and finally step 4: Evaluation on sufficient contributions by the use of the Morphological Analysis Format 3 (MAF3).

In Appendix 12.1 (page 145 – 150) a complete example is presented for this Research Analyses Protocol as applied in WS04.

3.3.4.2 Pre-answers to Research Questions for WS04

For RQ8 and RQ6 the steps that led to the results and answering of these RQ are presented.

RQ8 *Did loose introduction of the Morphological Overview lead to acceptance of the tool by the practitioners?*

To answer RQ8, three different data-sources were applied. The produced documents by the practitioners are used as data-source 1 for a quick scan by viewing the percentage of uptake of the MO in the different Design Task Settings during WS04. Data-source 1 used the on-spot-observation and photographs. This source was used for the preparation of a more detailed analysis using video-recordings as 2nd data-source, to determine the function-types and sub-solutions that were notated in the MO. In this way the type of use by the practitioners and the 5 teams could be delivered. Questionnaires by the practitioners are used as data-source 3. The results of the analysis using these 3 data-sources are compared for the answer to RQ8.

From the informal observations of the setting in WS04, there was evidence that the design teams were not averse to the use the tool. Figure 41 provides an example of one of the design teams working with the MO from the outset of the design task.

Figure 41 Morphological Overview discussed and used during Task 2, WS04 within the team-setting.

Analysis of data-source 1 showed that within the individual design-task all practitioners used the MO and on the team level 4 out of 5 used the MO (80%).

Data-source 2 used the video-recordings and the Video Observation Format (VOF) and Morphological Analysis Format (MAF) to analyze the data. The results for the 5 teams are organized in the MAF in Figure 42 in the overview per Design Task Setting the MAF was extended with the coding for the notation in the MO. This was done by adding the code (MO) behind the specific sub-solution corresponding to the reference function-type. In blue the coding and notations for MAF1, in black the coding and notations for MAF2. The total overview for all teams organizes MAF3. In the green box: realization-related function-types and sub-solutions. With the use of the reference-list for the 19 function-types (Figure 26, page 89) the different notated function-types are organized in the left column of Figure 42 from this initial picture alone it is clear that the teams did make a genuine effort to use the MO.

WS04 Team: 1-5 Task: 2 FUNCTION-TYPES (F) / SUB-SOLUTIONS (SS)								TOTAL SUB-SOLUTIONS (SS)
Rain / water proof	Double roof (MO) B3	Gutter (MO) B2, B3, B5	Glass roof (MO) B1	Buffer roof (MO) B2	Terrace roof B4			5
Temperature / protection	In 1st layer (MO) B3	Through cushion B2	Isolation / passive roof B4					3
Ventilation	In 2nd layer, between panels and water-proof layer B3							1
Heating & Cooling	Double roof black / white = energy use by differentiation B3	Floor heating roof system B4 (MO)	Water pump – sun – water = cooling system B5					3
Sustainable energy generation	Sun panels (MO) B1, B2, B3	Super natural ventilation / cooling system through double roof + wind + ventilation + sun (MO) B3	Vacuum wind energy B3	Bio-mass (MO) B2	Grey water (MO) B1, B4, B5	Vacuum elevator + wind energy (MO) B2	CO2-reduction through trees/plants (MO) B5	15
Sustainable energy generation	Kinematic energy (MO) B2	Second skin total building (MO) B1	Individual user manual / manipulation B1	Fishing / swimming pool = summer Ice skate = winter B2	Wind mill + big mill recreation (MO) B4	Melting snow system = water B4	Active roof (MO) B5	
Sustainable energy generation	Passive roof / super-isolated + ventilated B5							
Maintenance								
Safety	Cables (MO) B2	Anchor in roof construction (MO) B2						2
Construct & Build	Wood tile layer + waterproof layer + ventilation B3	Glass house frame B1	Shaped glass roof B1	Inflatable roof type 1 B2	Inflatable roof type 2 B2	Prefab components B4	Glass house frame B5	7
SUB-TOTAL REALIZATION F= 6 / 1 = 7 F in MO = 5								SUB-TOTAL REALIZATION SS= 24 / 12 = 36 SS in MO = 19
Fire-resistant								
Light / sun + protection	Absorption + reflection through white roof-color B3							1
Functions for the building / roof	Restaurant B3	Fishing pool B3	Kermis (MO) B1	Coupling functions building below (MO) B1	Multi-functional (MO) B1	Traffic-jam resistant B2	Glass-house (MO) B1, B2, B5	17
Functions for the building / roof	Roof garden (MO) B1, B4, B5	Recreation space – party space B1	Working space B1, B2	Camping (MO) B2	Swimming pool (MO) B2	Commerce space / sponsoring space B5	Terrace (MO) B4	
Functions for the building / roof	Dancing / disco (MO) B2	Recreation at home B5	Flexible use B5					
Architecture								
Shape	Double pitched B1, B2, B3, B5	Bent (MO) B2, B4	Pitched single (MO) B1, B2, B5					3
Construction								
Building Physics	Breathing foils under-construction B1, B3	Open construction B3						2
Costs / finance / benefit								
Utilities								
Material								
Climate								
SUB-TOTAL OBJECT F = 3 / 1 = 4 F in MO = 2								SUB-TOTAL OBJECT SS = 18 / 5 = 23 SS in MO = 11
TOTAL F = 9 / 2 = 11 TOTAL F in MO = 7								TOTAL SS = 42 / 17 = 59 TOTAL SS in MO = 29

Figure 42 Morphological Analysis Format for WS04, Task 2 with 5 teams.

To get a clearer picture of the extent of use of the MO, Figure 43 gives an overview of the average percentage of the total notated items (function-types or sub-solutions) for each team. The noteworthy results here are that the teams collectively included 11 out of 19 (58%) of the function types from the reference list. Similarly, 59% of these notated function types and 50% of the related sub-solutions were also notated in the teams; MO's. These numbers provide an early indication that the teams are prepared to accept the use of the MO as a meaningful Morphological Overview.

WS04 TEAMS	**TASK 2**	
	FUNCTION-TYPES	SUB-SOLUTIONS
B1	86%	63%
B2	63%	67%
B3	33%	31%
B4	57%	50%
B5	57%	37%
TOTAL AVERAGE	59%	50%

Figure 43 WS04: Overview notated function-types and sub-solutions in MO, as percentage of total notated function-types and sub-solutions.

Data-source 3, the pre-defined questionnaire, provided the final insight into RQ8. By verifying how the practitioners evaluated the use of the MO during the workshop, in their own practice and for future use. Here only the related WS04 is presented as average outcomes for the Questionnaires (Figure 44). The full overview of all questionnaires of WS03, WS04 and WS05 can be viewed in Appendix 13 (Figure 13.1, page 190).

WS04 QUESTIONNAIRE **A = Architect** / **C = Contractor** Rating from 1 – 5 (5 = most positive)	Use of MO – in general	Useful to stimulate use MO within practice	Expectation future use of MO
WS04 - A average direct / 8 out of 9 / 89%	3,4	2,2	2,5
WS04 - A average after 6 months / 6 out of 9 / 67%	**2,6**	**2,7**	**2,5**
WS04 - C average direct / 9 out of 9 / 100%	3,6	4,0	3,4
WS04 - C average after 6 months / 6 out of 9 / 67%	**3,0**	**3,5**	**3,5**

Figure 44 Average outcomes Questionnaire WS04 (fragment); questions related to use of the Morphological Overview (MO).

The response to the questionnaires both directly after the workshop (average 94%) and also after 6 months (average 67%) was positive. For the use of the MO during the workshop the rating was positive for both Architects and Contractors directly after the workshop (average 3.5 on the rating-scale). Although both practitioner-types are still positive after 6 months, it is striking that the Architects seem more critical about the use in the workshop compared with the Contractors. Overall the Architects are more critical in their ratings compared to those of the Contractors. In the rating after 6 months the roofers rate on average 0,7 higher compared to the Architects. This gives an indication that the Contractors experience the benefit of the MO more positively compared to the Architects. For the use of the workshop in combination with the MO this supports the purpose of the introduction of the tool in the collaborative setting. The Architects are more or less neutral and Contractors are positive concerning the future use of the MO in their practice as well as for the structural introduction in professional education.

Comparing the results of the 3 analyses shows a consistent positive tendency of the global use of the MO. Therefore the pre-test answer to RQ8 is as follows.

> The introduction of the Morphological Overview as Design Support Tool in the setting of WS04 led to the sufficient uptake of the tool in a sufficient way. The multidisciplinary design teams with different educational backgrounds were not averse to using the Morphological Overview, even when they had a choice not to use it. The 3 data-sources to analyze this RQ were sufficient and therefore adopted for the definitive testing.

The next RQ to be answered is RQ6:

RQ6 *Did both types of practitioners succeed in contributing realization knowledge?*

The previous workshops evaluated whether the general setting and the task type served to stimulate and facilitate interaction between the team members. However, in order to determine the overall value of the approach, it was important to evaluate to what extent the interaction in the teams represented task oriented knowledge. This was determined by the Research Analyses Protocol and the use of the first version of the Video Observation Format (VOF) as described in paragraph 3.4.1. It was also important to determine whether the CD teams were capable of contributing object and realization knowledge to develop an Integral Design for roofs that would reduce the risk of failures during the construction phase. The expected object and realization knowledge required for an Integral Design is contained in the reference list of function-types derived from the competence profiles of the Professional Organizations.

As stated, related to the problems in practice, especially the contributions related to realization-knowledge are important as a basis for an Integral Design. If we can determine notated realization-

knowledge introduced and exchanged by Architects and Contractors this indicates that the practitioners are acting as a Collaborative Design Team.

With the use of the Video Observation Format (VOF) the first indicated function-types from step 1 can be confirmed and entered in the MAF. These results are organized in Morphological Analysis Format 2 (MAF 2), which gives an overview of all notated contributions within the CD teams of Design Task Setting Task 2. This MAF is presented in Figure 42 (page 106), with in the left column the function-types from the reference list and on the horizontal axis; all related sub-solutions. In the green box: realization-knowledge.

Overall, there was a good mix of the desired function-types within all teams. What was observed was that within the design task all teams also notated the majority of expected realization related function-types such as 'Rain-water proof', and 'Temperature proof'. In addition, important function-types related to the sustainable energy use such as Ventilation, Heating & Cooling and Sustainable Energy Generation were also notated by the teams.

To determine if the knowledge exchange was also sufficient to constitute effective collaboration, the Morphological Analysis Format 3 (MAF 3) was used to identify the contributed realization-knowledge. These function-types and sub-solutions are organized in the green box of Figure 42 (page 106). The first view shows that of the realization-related function-types; Maintenance and Fire-resistance were not notated by any of the 5 teams of WS04. Of all function-types also 'Construction' and 'Material' as object-knowledge were not used by the teams.

The overview of the notated function-types and sub-solutions of Teams B1 to B5 is given in Figure 45. This overview shows that an average 40% of the reference function-types were notated, of which 29% were object-related and 55% were realization-related. With the Research Analyses Protocol it was only possible to determine the contributions on the team-level and not on the individual level. This gives a positive indication that the teams understand the need to contribute realization-knowledge.

WS04 KNOWLEDGE TYPE	**SOLUTION-TYPES**	**TASK 2 B1**	**TASK 2 B2**	**TASK 2 B3**	**TASK 2 B4**	**TASK 2 B5**	**AVERAGE / PERCENTAGE**
OBJECT	FUNCTION-TYPES (F) (14)	3	2	5	2	4	3,2 (29%)
	SUB-SOLUTIONS (SS)	9	9	6	3	8	7,0
REALIZATION	FUNCTION-TYPES (F) (11)	5	6	4	4	3	4,4 (55%)
	SUB-SOLUTIONS (SS)	6	12	7	8	8	8,2
TOTAL F(25)		**8**	**8**	**9**	**6**	**7**	**7,6 (40%)**

Figure 45 Overview: variety of notated function-types and sub-solutions within the team-setting during the WS04. Task 2: with use of the MO.

Based on these results the next pre-test answer to RQ6 can be given.

> Within the setting of WS04 it was not possible to answer this question directly by looking at individual contributions. Rather, these contributions must at this point be inferred from the team picture. On the basis of the assumptions made earlier that each discipline will possess the majority of a particular knowledge type, if both object and realization function-types are identified, then there is an indication that the individual practitioners for the disciplines did indeed play an active part in the team collaboration. This indeed proved to be the case. Thus, on this basis, it was possible to determine

that realization-knowledge was contributed by teams complementary to object-knowledge.

To show how this Research Analyses Protocol in WS04 was executed in detail an example can be viewed in Appendix 12.1.2. (Example 2, page 146 – 150).

In brief the following results could be determined in WS04 related to RQ8 and RQ6; the adaption and use of the Morphological Overview by practitioners in a collaborative setting (RQ8), in general and the notation of realization-related function-types and sub-solutions by teams during the design process (RQ6).

In terms of the first RQ8 related to WS04, the acceptance and use of the Morphological Overview (MO), all teams as well as individual practitioners used the MO when it was loosely introduced to individuals and teams. This gave an indication that the practitioners were in majority positive about the use of the MO and that they were eager to use the tool in their own way. This conclusion is based on the outcome of the used analysis of data-sources as well as by the feed-back from the practitioners directly after the workshops and after 6 months from the results of the questionnaires. An overview of these results is presented in Appendix 13 (Figure 13.1, page 190).

The use of the MO in general was average rated after 6 months, on the scale of 1-5, with 2,6 by Architects and 3,0 by the Contractors. On the question on the usefulness to stimulate the use of the MO in practice the score was even more positive: 2,7 for Architects and 3,5 for the Contractors. Their expectations on the future use of the MO were rated as follows: 2,5 for Architects and 3,5 for Contractors.

Concerning the RQ6 Goal, the determination whether the practitioners could contribute realization-related function-types and sub-solutions it might be concluded as follows. Within all teams contributions were made in object- as well as realization-related function-types and sub-solutions. This gives an indication that the teams act as Collaborative Design teams. However the results show also that a complete and balanced use of all reference function-types is difficult.

3.3.4.3 Results for the research improvements for Goals of WS04

In WS04 two main research improvements were executed to prepare answers to RQ6 and RQ8.

For RQ8, related to the use of the Morphological Overview analysis of three data-sources were used; on spot view and produced documents, use of the Video Observation Format and pre-defined questionnaires. With the use and analysis of these data-sources as used research improvements could be finalized because RQ8 could be answered sufficiently.

To answer RQ6 related to the Design Team the application of the use of the Video Observation Format and the Research Analysis Protocol to determine the contributed knowledge has to be evaluated as the second Goal for WS04. The first research improvement was related to the development of the VOF and the second one to the development and use of the MAF3. With the VOF contributions of object- and realization-knowledge could be observed and the data collection could be refined. The MAF could be used efficiently to analyze the team contributions.

The Research Analyses Protocol to apply the VOF and the MAF made it possible to collect and determine on team level the sufficient contributions by using the produced documents, photographs and video-recordings. The VOF was specifically developed to observe knowledge exchange between the practitioners in a Design Team. Although, with the Research Analysis Protocol it was only possible to analyze on team level the explicitly notated knowledge. To analyze the explicitly notated knowledge on individual level insight into the individual contributions was more valuable and necessary related to

the collaborative setting. This was organized by adding an extra fifth analyzing step with the focus on the individual contributions related to the type of participant and the contribution of the related knowledge-types; object- and realization-knowledge.

The result for the application of the Research Analyses Protocol was an Improved Research Analysis Protocol with the following analyzing steps. Step 1: use of the Morphological Analysis Format 1 (MAF1); step 2: use of the Video Observation Format (VOF); step 3: use of the Morphological Analysis Format 2 (MAF2); step 4: evaluation on sufficient contributions on team level by the use of the Morphological Analysis Format 3 (MAF3); finally step 5: determination of individual contributions (Architect and Contractor) of object- and realization-related function-types and sub-solution per communication-type (speech, sketch, MO).

3.3.4.4 Overview DRM Stages, the corresponding Research Questions and Goals

From the results from WS04, Research Questions RQ6 and RQ8 and corresponding Goals the next step is to develop and apply research improvements related to RQ9 and key-component Tool (Morphological Overview). The finalized step of WS04 is marked in yellow in the overview DRM stages in Figure 46. The Research Questions and related Goals for WS05 as next step in the research project are presented in the same Figure 46.

	DRM Stage	Research Question(s)		Goals
1	**Research Clarification**	**RQ1**	*What type of knowledge should the competent architect, roofer and installer possess?*	Problem identification+answers RQ1-RQ2
		RQ2	*When and how should this knowledge ideally be exchanged within a Collaborative Design Team?*	Development of RQ3 and RQ4 Hypotheses and Measurable Success Criteria
2	**Descriptive Study 1**	**RQ3**	*What factors hindered the success of the Case Study projects?*	Problem is expressed in practice
		RQ4	*What are the necessary key-components of the Technological Design?*	Key-components identification Development of: RQ 5-6-7-8-9
3	**Prescriptive Study**			Pre-Answers to: RQ 5-6-7-8-9 Research Improvements
	WS01 *Students workshop*			Determine if the setting encourage interaction Determine if Observation Format is suitable
	WS02 *Students workshop*			Development of alternative observation and analysis methods for the effects of use of the (loosely introduced) Morphological Overview Determine the effect of the use of the (loosely introduced) Morphological overview on knowledge exchange
	WS03 *In-company workshop*	**RQ5**	*Were the tasks sufficiently complex to require the collaboration between the practitioners?*	Evaluation of the analyses to determine the complexity of the Design Task; a quick-scan, the Functional Analysis, pre-defined questionnaires
		RQ7	*Did the face-to-face setting provided by the workshop allows collaboration between the practitioners working on the design task?*	Evaluate the use of the developed Quick-scan, the Observation format 2 and Morphological analysis format
	WS04 *Practitioners workshop*	**RQ6**	*Did both types of practitioners succeed in contributing realizations knowledge?*	Evaluate the use of the developed Video Observation Format and the Research Analysis Protocol
		RQ8	*Did loose introduction of the Morphological Overview lead to acceptance of the tool by the practitioners?*	Evaluate the adoption and use of: the Morphological Overview: Quick-scan, Morphological Analysis Format 3 (MAF3) and Pre-defined questionnaires
	WS05 *Practitioners workshop*	**RQ9**	*When used did the Morphological Overview stimulate for the exchange and structuring of knowledge between the practitioners?*	Evaluation of the effect of the use of the Morphological overview Evaluation of the use of: the Video Observation Format (VOF), the Video Interaction Format (VIF) Development and application of the Collaborative Design Workshop lay-out Finalizing of Research improvements
4	**Descriptive Study 2** *Practitioners Workshop*	**Test RQ 5-9**		Answers to: RQ 5-6-7-8-9 Testing the key-components and Research improvements in the Definitive Collaborative Design Verification of the key-components and the analyzing tools: VOF, VIF, MAF3, and Evaluation Formats Evaluation of the Hypotheses and Measurable Success Criteria

Figure 46 DRM-stages with corresponding Research Questions and Goals.

3.3.5 WS05: WORKSHOP SERIES 5

Workshop series 5 (WS05) was a one day workshop with 10 practitioners; 5 Architects and 5 Contractors that took place at two conference rooms at Kropman at Utrecht Leidse Rijn on the 5th of June 2008. The division of the practitioners to teams was organized in the same way as for WS04. The workshop started with an individual design task without the use of the Morphological Overview (MO). This was applied to get especially the Contractors acquainted to a roof design task. After the first design task the practitioners were split in 2 groups X and Y, with numbering of each practitioner in order of subscription. Group X consisted of 2 Architects and 2Contractors and group Y with 3 Architects and 3 Contractors. For Design-Task 1, group X1 (teams A1, A2) started without the MO and group Y1 (teams B1 to B3) with the MO. Design-task 2 with changed teams group X2 (teams B5, B6) started with the MO and group Y2 (teams A5, A6 and A7) without the MO.

The Goals of this WS05 were:

1: Evaluate the effect of prescribing the use of the MO to the design teams (method: one session without followed by a session with then comparing results)

2: Evaluate the use of Video Observation Format (VOF) and Video Interaction Format (VIF) related to individual contributions of practitioners as part of the Improved Research Analysis Protocol

3. Apply the Workshop lay-out for practitioners and the research

This was organized to answer Research Question RQ9 of the 9 Research Questions:

RQ9 When the Morphological Overview is used, did the tool allow for the exchange and structuring of knowledge between the practitioners?

For answering the RQ9 and on basis on the previous findings application of the following research improvements were the Goals for this WS05.

3.3.5.1 Application of the research improvements: modifications of formats for observation and analysis for WS05

Photographs

A modification was that all photographs were coded afterwards according to Workshop-number (WS0n), Design Task Setting (Tn), Team-number (An) and number of photograph (n). Photographs were taken by trained assistants.

Video-recordings.

The following modifications where made: all 6 available video-cameras were used, with microphones. The lay-out of the working-spaces for the teams was enlarged so that there was enough space in between and there was no interference with sound between the teams. Video-tapes had to be converted to digital-format. Video-tapes were coded with stickers; Workshop-number (WSn), Design Task Setting (Tn), Team-number (An).Video-preparing as well as video-recordings were done by trained assistants. Figure 47 shows the typical working lay-out which was used in WS05 and in the DWS: each team with a separate working desk and private space, observation through video-camera and microphone, photographs each 10 minutes of produced items and loose observation by trained assistants.

Figure 47 Example of working situation of teams in setting WS05; as used in the DWS.

Video-Observation Format (see also 3.7.2 for Protocol, page 177)

The Format for Video-Observation as used in WS04 was adopted for WS05. The only aspect that changed was the listing for the function-types. In 2009 new competence-profiles from the Professional Organizations were available (*Competence-profiles / BNA (Dutch Association of Architects) / 2009 Competence-profiles / EVC + Hoofd Bedrijfsschap Ambachten (HBA) + Bouwradar / 2009-Competence-profiles / Rijnland Advies + TVVL (Dutch Society for Building Services) / 2008)*. The used function-type reference-listing is derived from these competence-profiles (see Appendix 2, page 5 - 7).

By studying the new competence-profiles form the Professional Organizations, the existing reference list with 19 function-types was extended with 6 function-types to 25 function-types in total (Figure 15, page 71). For realization-related function-types 'Comfort & Health', 'Accessibility' and 'Operational' were added. Orientation & Sight, Sustainability, Orientation & Sight, Sustainability, Users and Flexibility were added as object-related function-types; Climate was removed from the list in Figure 26 (page 89). The used definitions can be viewed in Appendix 3. The other characteristics are the same as the described Video-Observation Format in WS04.

The format is shown in Figure 48 on the next page, with the function-types in the left column, as derived from the competence profiles as now available from the Professional Organizations. This reference-list for the function-types is the same as Figure 15 on page 71 (25 function-types). In the green box the realization-related function-types are marked.

Functionalities / Solutions WS Team: Task:	Participant	Used	How		T 21 –22 minutes	T 23 -
f1= rain / water-proof f2 = temperature proof f3 = ventilation f4 = maintenance f5 = safety f6 = heating & cooling f7 = sustainable energy generation f8 =construct & build f9 = comfort & health f10 = accessibility f11 = operational f12 = light / sun-use & protection f13 = functions for building & roof f14 = orientation & sight f15 = construction f16 = costs & finance & benefit f17 = architecture f18 = sustainability f19 = building physics f20 = fire protection f21 = utilities f22 = shape f23 = material f24 = users f25 = flexibility > sent < receive - alone	ARCHITECT	only as function	speech / talking			
			on paper	sketch		
				MO		
		related to design > combination	speech / talking			
			on paper	sketch		
				MO		
		related to design > new	speech / talking			
			on paper	sketch		
				MO		
	CONTRACTOR	only as function	speech / talking			
			on paper	sketch		
				MO		
		related to design > combination	speech / talking			
			on paper	sketch		
				MO		
		related to design > new	speech / talking			
			on paper	sketch		
				MO		

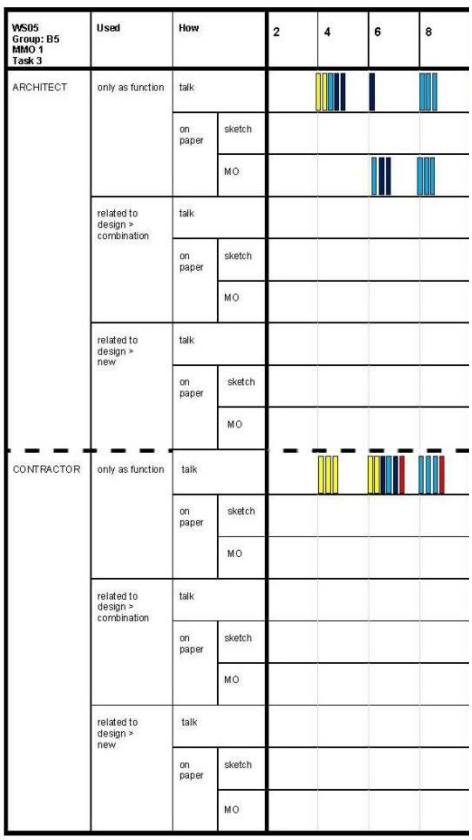
Figure 48 Video Observation Format (fragment); Time-frame 20-30 minutes out of 60 minutes total.

Figure 48 shows a fragment of the used Video Observation Format; in the left column the reference function-type list used *(what).* Second column shows the two practitioners within the team *(who);* the upper half of the format is used to notate activities of the Architect related to the design task; the lowest half those of the Contractor. Third column contains the characteristics of the function-types (related to in general to function; related to the design-task; related as new item to the design task). Column four is related to the way the activities are executed *(how);* by speech, sketches and/or the use of the MO. Columns next are the time-frame boxes of each 2-minutes, with on one page a 10 minutes overview *(when).* In the green box the realization-related function-types from the reference-list.

Video Interaction Format (see also 3.7.2 for Protocol, page 177)

To support the Video Observation Format related to the type of activity in interaction between the different practitioners during the design-process an additional format was needed as shown in WS04. This Video Interaction Format captures in one overview, the development of interaction-type (send or receive) and communication-type (speech, sketches, MO) between the practitioners of the team. The development of the Format took place during the WS05.

For the first version of the Video Interaction Format Pre (VIF Pre) the first four columns of the Observation Format (VOF) were adopted to make it easy to handle and compare. The layout of the format was simplified slightly by replacing the need to record chunks of text with arrows, which allowed for one A3 sheet to be used to capture the entirety of a one-hour session. In the VIF Pre a stripe-type coding was used where all the characteristics were symbolized in colors of the stripe (Figure 49). In the first try-out it appeared that a main characteristic should be more prominent and visible; 'who' of the team is the 'sender' and who the 'receiver' (interaction-type) of the communicated function-type or sub-solution and 'how' (talk, sketch, MO).



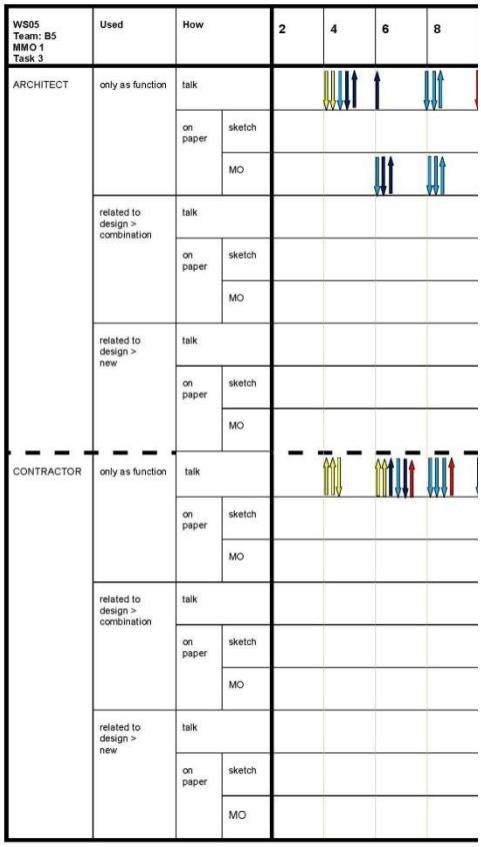


Figure 49 (left) First version of the Video Interaction Format Pre, with stripe-coding.

Figure 50 (right) The final version of the Video Interaction Format, with colored arrows.

The final version of the Video Interaction Format (VIF, in Figure 50 and 51) contains one format for all found function-types and sub-solutions represented as color-coded arrows. The color-coding was used for the function-types (red or dark-blue) and sub-solutions (yellow or light-blue) related to communication-type (talk, sketch or MO) and interaction-type (send, received). The color-coded arrows can be placed in a specific box related to type of used in the design (only as function, related to the design – as combination, related to the design – as new solution) and communication-type (talk, sketch, Morphological Overviews). Horizontal axis is the time-schedule with the 2-minutes time-zones

up to 60 minutes (*when)*. Vertical axis shows the knowledge representations. Each block-segment in colour represents one used functionality or sub-solution; the colour represents the interaction-type. The direction of the arrow points out who of the participants is the sender or receiver. The position of the arrow in the VIF on a horizontal row is related to the communication-type which is used and when it is used. When a function-type or sub-solution is send- and received through one of the communication-types this item is processed. Coding system arrows:

Dark blue: send / received function-type, processed

Light blue: send / received sub-solution, processed

Red; send / received function-type, not processed

Yellow: send / received sub-solution, not processed

In the protocol which is presented in section 3.7.2, part 2.1 IIIB (page 184), the basic situations related to the use of this notation is explained.

Although the focus is on notated object- and realization-related function-types and sub-solutions (dark blue and light blue arrows), the other notations are part of the total array of interaction and communication between the Architect and Contractor related to the design task. So the total array of interaction and communication gives a view on the overall interaction between practitioners during the design process related to the design task.

Finally, an example of the used VIF, showing a sequence of 60 minutes, is presented in Figure 51. In the left four columns with the characteristics of activities (who, how, when); next boxes are the time-frames of each 2 minutes which contain ‘what’ is communicated. The format views 1 design-session in one overview of 60 minutes. This Figure is an example of how it is used for the analysis of one team within WS05 with the specific coding.

With the Video Observation Format and the Video Interaction Format the following aspects can be determined:

- Amount and type of function-types (Fn) and sub-solutions (SSn); processed and not processed

- Sender / receiver of function-types and sub-solutions (Architect, Contractor); when processed, the used interaction-types and balance and effectiveness in interaction

- Types of communication (speech/talk, sketch/scheme etc. or use of Morphological Overview); notated or not; when processed, the used communication-types

- Related to design (in general terms; as function, related to design specific or as a new term)

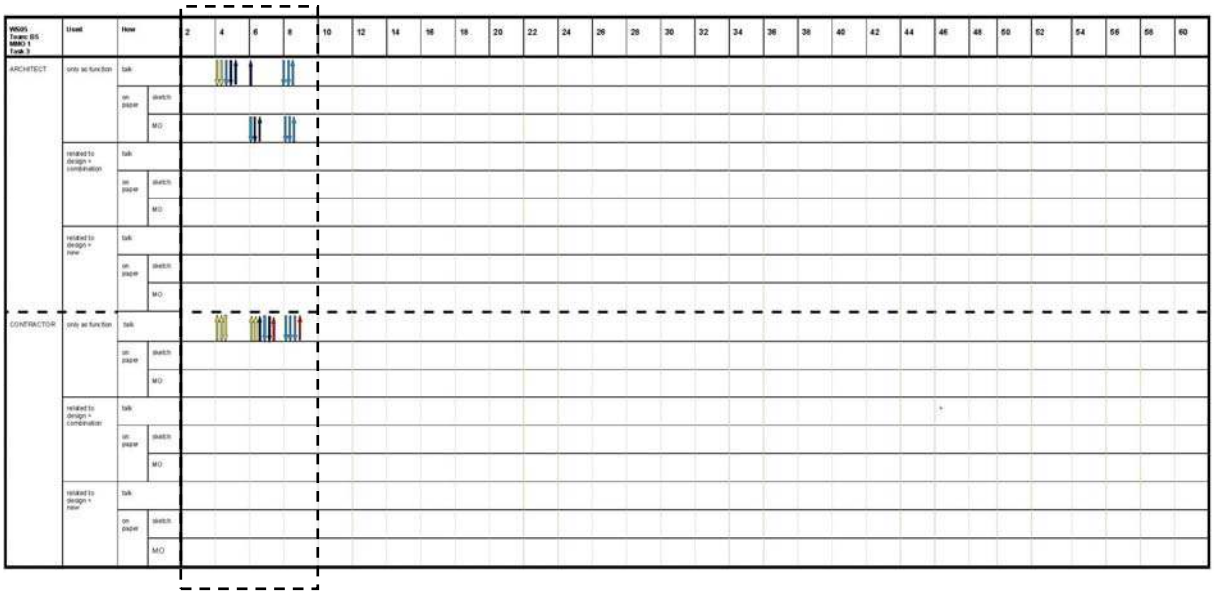


Figure 51 Video Interaction Format (VIF), showing a sequence of 60 minutes (see Figure 47)

Morphological Analysis Format

The Morphological Analysis Format organizes one format for all notated function-types and related sub-solutions as notated by the teams for each design task session. On the vertical axis the realization-related and object-related function-types are organized with the reference function-type listing. The categories used in the listing are similar as that of the Video Observation Format and derived from the competence profiles from the Professional Organizations. The coding for the use of the Morphological Analysis Format was organized as follows:

- Team: what team did notate the specific function-type and/or sub-solution: coding Team = letter + number (e.g. A3)
- Use of MO: when the sub-solution is also notated in the MO produced by the team: coding = MO in the box of the specific sub-solution
- Use of Realization knowledge: when a sub-solution is notated as realization knowledge by the team

On page 71, in Figure 15 the overview of the reference-list for these 25 function-types are presented. In Appendix 3 the corresponding list of used definitions for these function-types can be viewed.

Improved Research Analyses Protocol

With the Research Analyses Protocol as developed and applied in WS04 it was possible to observe and analyze the knowledge exchange on team-level. The necessary insight in the individual interaction and contributions could not be determined. Therefore a more fine-grained step was needed with the use of an additional observation format; the Video Interaction Format combined with the VOF and the MAF in step 3, 4 and step 5. This Improved Research Analyses Protocol can be described as follows:

1. First step: views all the produced documents and collects the notated function-types and sub-solutions with the reference list of function-types. The collected data are organized per team into the first draft of the Morphological Analysis Format 1 (MAF 1). Photographs are used to frame the time.

This first step is to get acquainted to the data of the different Design Tasks documented by the practitioners and to get a first insight into these data.

2. Second step is to confirm the found function-types and related sub-solutions from step 1. This is done by the use of the Video Observation Format (VOF) for each video-taped team within a specific Design Task Setting. In this Format the *what, how, when* and *who* of the specific communicated function-types can be determined. Most important is the influence of the use of the Morphological Overview for structuring and exchange of knowledge between the practitioners. All video-taped teams within one Design Task Setting are transcribed into the Video Observation Format (VOF) with a specific coding for workshop, task and team. In the format a specific coding is used for type of functions and sub-solutions related to the reference function-type list (25 function-types, Figure 15, page 71) for object-related and realization-related function-types.

3. Derived from the Video Observation Format (VOF) the Video Interaction Format (VIF) is made for each video-taped team within a specific Design Task Setting. This Interaction Format is a graphical way to view *how* the types of communication used in interaction between the practitioners are related to the *what, when* and *who* in a more comprehensive way.

4. The data from the Video Observation Format (VOF) and Video Interaction Format (VIF) are then put into the Morphological Analysis Format 2 for each monitored team. In this second draft of Morphological Analysis Format 2 (MAF 2) the found and confirmed sub-solution is added to the items from MAF 1. Items from MAF 1 are in blue, added items are in black. Additional in this step is to combine the overviews of the individual teams in an overview for all teams within a specific Design Task Setting; MAF 3. The total amount of found realization knowledge notated during the design process is counted and leads to the final overview.

5. In combination with the data of the Video Observation Format (VOF) and the Video Interaction Format (VIF) per Design Task Setting and team an overview is organized for: type of practitioner (Architect, Contractor), type of function-types and sub-solutions notated (object- and realization-related) and communication-type (speech, sketch, MO).

3.3.5.2 Pre-answers to the Research Question of WS05

The first aspect in this collaboration and knowledge exchange is related to, as shown in the pre answer on RQ6 (page 107), with the introduced and notated, realization-related function-types and sub-solutions within the CD Team by the different practitioners. The practitioners can document the exchanged knowledge in several ways, and are free to choose to do this through sketches, schemas and / or the use of the Morphological Overview.

The influence of the Morphological Overview though can be determined by the notated function-types and sub-solutions in the Morphological Overview during the design-process by the different practitioners as basis for the design. The other characteristic of the Morphological Overview is that it can structure the function-types and sub-solutions: object-related of realization-related. The expectation in the Collaborative Design Workshop is that Architects should contribute more object-related function-types and sub-solutions were Roofers should contribute more realization-related function-types and sub-solutions.

The results presented are related first on the contributions of the CD teams and second on the individual contributions within the CD teams as part of RQ9.

CD team contributions in the Morphological Overview

By using the Improved Research Analyses Protocol the CD Team contributions can be determined as first result of Research Question RQ9. The overviews presented below are organized by the different Design Task Settings where the Morphological Overview was loose introduced: Group Y1 for Design Task T2 for CD-teams B1, B2 and B3 and Group X2 for Design Task T3 with CD-teams B6 and B7.

In order to allow for comparison, two alternative conditions were used in this setting, one in which the Morphological Overview was used first and then not used, and vice versa. The comparison of all Design Task-settings is presented in Figure 52. The used reference-list of the function-types has 25 function-types in total of which 14 are object-related function-types and 11 are realization-related function-types. The percentages for the object- (14) and realization-knowledge (11) refer to the total amount of the function-types within the separate knowledge-types of the reference-list. The percentage Total refers to the total amount of all average notated function-types related to the 25 function-types of the reference-list (100%). For example; when notated 3,5 out of 14 object-related function types, this is 3,5 out of 14 object-related function-types of the reference-list and the percentage is 25%. For the Total Function-types: 6 out of 25 function-types are 24%.

WS05 Knowledge Type	**Task 2 / NMO / X1** **A3, A4 (2)**	**Task 2 / MO1 / Y1** **B1, B2, B3 (3)**	**Task 3 / MO1 / X2** **B5, B6 (2)**	**Task 3 / NMO / Y2** **A5, A6, A7 (3)**
Object-related Function-Types (F) (14)	3,5 (25%)	3 (21%)	3,5 (25%)	2 (14%)
Realization-related Function-types (F) (11)	2,5 (23%)	2,5 (23%)	3,5 (32%)	1,3 (12%)
Total Function-types F (25)	6 (24%)	5,5 (22%)	7 (28%)	3,3 (13%)

Figure 52 WS05: overview of all Design Task Settings (T2, T3) and teams of group X and Y; average amount of the total notated function-types and amount of sub-solutions. Percentages related to function-types.

For the contributions of the individual teams the influence of the use of the Morphological Overview (MO) can be compared with the influence of the order of introduction of the MO. This comparison gives the following results.

First result is related to the introduction of the MO (Figure 52). The results of Design Task-settings when the MO is loose introduced are presented first. In these groups: group X2: 28% and group Y1: 22% of all reference function-types were notated. In the other two Design Task Settings, group X1 notated 24% and group Y2 notated 13% of all reference function-types. So, when the MO was used equal or more function-types were notated compared with the Design Task Settings without. Average also equal or more realization-related function-types and sub-solutions were notated when the MO was used (group Y1, X2) compared with the Design Task Settings without use of the MO (group X1, Y2). When the MO was loose introduced in average about 24% of the function-types were notated.

Second results include the influence of the order of introduction of the MO. Group X follows a routing from a more traditional setting where the practitioners can work with their own methods (group X1) followed by a setting where the MO was loose introduced (group X2). Group Y follows the opposite routing. What can be determined from Figure 52 are the following related results. In the situation were the MO was loose introduced in the first design task (Group Y) for both object- and realization knowledge fewer contributions were made in the second design task without the MO. In group Y, 92% less realization-related contributions (Y1: 23%, Y2: 12%) and 67% less object-related contributions (Y1: 21%, Y2: 14%). In group X were the first design task started without the MO and in the second design task the MO was loose introduced the same tendency could be observed. For contributed realization-related items an increase of 72% (X1: 23%, X2: 32%) for realization-knowledge and equal

contributions for object-related items (X1: 25%, X2: 25%). For group Y the use of the MO has a less positive effect in percentage notated items and a negative effect on the Design Task Setting without working with the MO (group Y2) compared with group Y1. This tendency can be identified for as well object- as realization-related knowledge types.

This result could be explained by the fact that in a routing where the Contractor in interaction with the team can step by step get acquainted to the design setting and a supportive tool gives better circumstances for contributions compared with the opposite routing. Although in group Y the notated realization-related knowledge is positive in the first time use of the MO (group Y1) a negative tendency is observed in the following 'traditional' setting (group Y2). In the traditional setting (group Y2) the supportive tool is not available and gives the Architect the possibility to choose on basis of his experience his own tools or working methods. This situation shows to be less effective. Sub conclusion is that the order of introduction for setting group X should be adopted.

Individual contributions in the Morphological Overview

The individual contributions related to the use of the Morphological Overview (MO) and related to the notation of the different function-types for all Design Task Settings are presented in Figure 53 and Figure 54. This is a summary of the results extracted from the different Video Observation- (VOF) and Video Interaction Formats (VIF) for each team in a specific Design Task Setting. These results are derived from the step by step analysis from the VOF; these results are presented in Appendix 5 (page 13 – 21). Referring to the Research Question RQ9 the focus is on the effect on the contributions when the MO is used. While in WS05 also the order of introduction of the MO was applied only part of the RQ9 could be applied. The focus here is on the application of the VOF and VIF and the influence of the order of introduction of the MO related to contributions of object- and especially realization-knowledge.

In the overviews in Figure 53 and 54 the average all notated items for object- and realization knowledge (function-types and sub-solutions) per Design Task Setting are organized.

WS05 PARTICIPANT TYPE	KNOWLEDGE-TYPES	TASK 2 NMO / X1 A3, A4 (2)	TASK 2 MO1 / Y1 B1, B2, B3 (3)	TASK 3 MO1 / X2 B5, B6 (2)	TASK 3 NMO / Y2 A5, A6, A7 (3)
ARCHITECT	OBJECT	11	17	21	6
	REALIZATION	7	8	14	3
A TOTAL		**18**	**25**	**35**	**9**
CONTRACTOR	OBJECT	9	6	3	9
	REALIZATION	3	7	7	3
C TOTAL		**12**	**13**	**10**	**12**

Figure 53 WS05 Overview: percentages of average notated function-types and sub-solutions in the MO per practitioner-type.

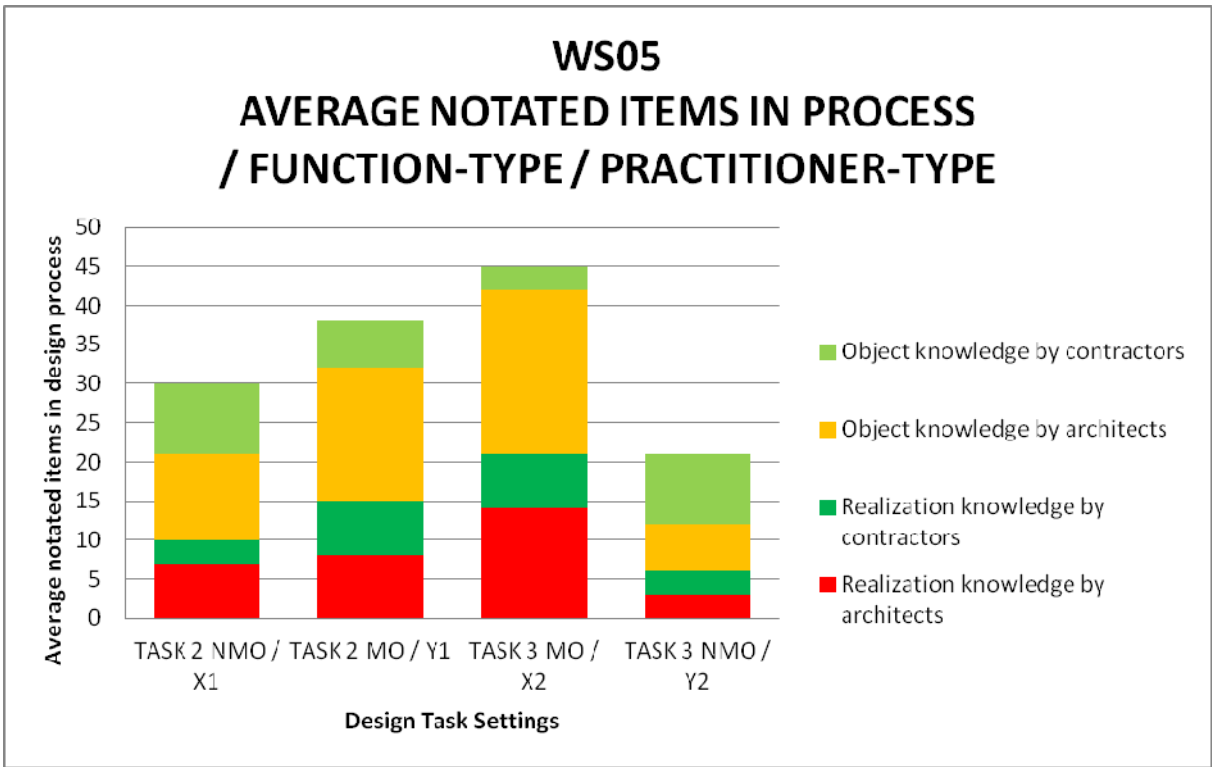


Figure 54 WS05. Overview: the average notated function-types and sub-solutions notated in the MO per practitioner-type. Graphical representation.

Related to Figure 53, which gives an overview of the different Design Task Settings viewed in WS05, a brief summary of how the WS05 was organized is presented in Figure 54 On the horizontal axis the two settings are organized. In the first setting group X starts without the MO (X1) and then is asked to repeat the same task with changed teams after the MO has been loosely introduced (X2). In setting two, Group Y starts after the loose introduction of the MO (Y1) and, after changing teams, without the MO (Y2). On the vertical axis the average of notated items (function-types and sub-solutions) per practitioner-type (Architect and Contractor) are organized. The items related to the contributions of the Architect are yellow (object-related) and red (realization-related), items related to the contributions of the Contractor are light- (object-related) and dark green (realization-related).

The main results to be drawn from Figure 53 and Figure 54 are as follows:

The table and graph of Figure 53 and Figure 54 show that in average the Morphological Overview (MO) was used both by Architects and Contractors, although with more contributions in the MO by Architects compared to Contractors. This can be viewed in Figure 53 in the result-row A Total (Architects) and C Total (Contractors). What also can be observed is that in the settings when the MO was not introduced (X1 and Y2), the contributions of the Contractors was higher in group X and slightly less in group Y. compared with the Design Task Setting were the MO was loosely introduced. There are two possible explanations for this tendency: First, since in this condition the practitioners started immediately in the team setting, the Contractors may have been especially motivated to contribute within the team-setting in. In other words, was adopted by the Contractor. Second, the MO is by nature a Design Support Tool; its introduction may be favored by the Architect, as its use is assumed to chime with the Architect's normal practices, whereas this is not the case for the Contractor.

Related to the realization-related contributions (dark-green and red in Figure 54) of the Contractors and Architects there is a tendency to notate more realization related function-types when the MO has been loosely introduced. For realization-related items by Architect for group X there is a doubling (X1 /

NMO: 7, X2 / MO: 14) and when in the contrary order also a contrary tendency in group Y (Y1 / MO: 8, Y2 / NMO: 3). When compared with the average realization-related contributions for Contractors the same picture emerges (X1 / NMO: 3, X2 / MO: 7; Y1 / MO: 7, Y2 / NMO: 3). These results give an indication that the order of the introduction of the MO influences the balance of the contributions for realization-knowledge by both practitioners. The pre-answer to the RQ9 is as follows:

> When the Morphological Overview was used it did allow for the structuring of the contributed knowledge. It was noticeable on the team level and individual level that the Morphological Overview served to stimulate balanced contributions of object- and realization-knowledge. However, limitations were determined in the effect of the Morphological Overview during the design process. Even when the Morphological Overview was used, about 24% of the function-types in the reference list were notated. Finally, the most optimal setting turned out to be the Practice Setting where the design-task is organized without the Morphological Overview followed by the Design Task Setting with loose introduction of the Morphological Overview (group X).

3.3.5.3 Results for the research improvements for Goals of WS05

The results for the research improvements of WS05 can be formulated related to the Goals below.

1: Evaluate the effect of loose introduction of the MO to the design teams (method: one session without followed by a session with then comparing results). The results for the order of introduction of the MO was that the setting were first the MO is not loose introduced followed by the setting were the MO is loose introduced is the most optimal. This is related to the contributions of realization-knowledge by the Contractors. In the proposed optimal setting it is also possible to determine in more detail the RQ9 on the use of the MO related to the situation were both Architect and Contractor use the MO. Finally also the situation were both Architect and Contractor notate realization-knowledge in the MO can be explicated.

2: Evaluate the use of Video Observation Format (VOF) and Video Interaction Format (VIF) related to individual contributions of practitioners. With the use of the VOF it was possible to effectively determine knowledge exchange in the different Design Task Settings of WS05. The practical use of the VIF was developed into a format which can give insight into the type of interaction between the practitioners within the Design Task Settings. The Improved Research Analysis Protocol, consisting of five steps and the VOF, the VIF and the MAF, proved to be an efficient and effective protocol to organize and apply these analyzing steps.

3. Application of the Workshop for practitioners and the research. Related to the introduction of the MO and the effectiveness for knowledge exchange between the Architect and Contractors the Workshop was executed. However, to get more insight into the effect of the MO related to use interaction and knowledge exchange the used lay-out for WS05 was proposed to change into a lay-out where different steps of loose introduction of the MO could be compared. This lay-out is presented in Figure 55.

With these positive evaluations of the research improvements related to RQ9 can be finalized and used for testing in the Descriptive Study 2.

3.3.6 OUTCOMES FOR THE PRESCRIPTIVE STUDY:

The two general Goals for the Prescriptive Study are, first: to introduce and develop research improvements related to the key-components (Design Task, Collaborative Design Team, Practice Setting, Design Support Tool) and second: to finalize these research improvements in order to test the key-components in the Collaborative Design Workshop. These research improvements were guided by the Research Questions related to these key-components and aspects to analyze the Results on the Answers of the RQ's. Aspects were the research improvements related to: workshop setting,

analyzing steps and used formats for observation, analyzing and evaluation. Through the Workshop Series WS03 and WS05 (June 2007-June 2008), different aspects of the key-components; Design Task, Collaborative Design Team, Practice Setting, Design Support Tool., are developed.

This development was realized by providing answers to the related Research Questions based on the outcomes of the executed workshops. As shown in the prescription of the outcomes of each workshop series and the design results, all Research Questions were answered based on the newly derived knowledge. What follows below is a short overview of these results related to the key-components. This overview is the basis for the testing of the key-components in the Definitive Workshops of Descriptive Study 2.

The outcomes for the Prescriptive Study are presented in two ways, Outcome 1: Key-components, derived from the answers to the RQ, Outcome 2: the Collaborative Design Workshop consisting of the workshop lay-out, formats for observation, analyzing and evaluation, the Improved Research Analyses Protocol.

OUTCOME 1: KEY-COMPONENTS

KEY-COMPONENT C1: DESIGN TASK

What became clear is that in the different workshop series each of the tasks was sufficiently complex to require collaboration between the practitioners. This was observed in the following results from 3 data-sources. The first indication of sufficient complexity was that in the different Design Task Settings the practitioners relied on a range of different available media (notes, sketches, MO). This suggests that the teams needed to decompose the problem and view it from a number of perspectives in order to reach an adequate solution. Another observation is that the teams had to deliver real effort to fulfill the design-task within the time-limitation of 60 minutes per task. It was never the case that a team or an individual completed the task with a significant amount of time to spare.

A second outcome is that for the different design tasks the practitioners notated a variety of function-types and sub-solutions. Thus, it was not the case that the task was simple enough to suggest an off the shelf solution. If this was the case, then we could have expected the teams to arrive at the same design solutions. Finally, the results of the questionnaires for the practitioners administered directly after the workshops and after 6 months confirm the complexity and relevance of the tasks set.

The conclusion is that the used tasks in the Workshop Series can be adopted for the final testing in the Definitive Collaborative Design Workshop. An overview of these tasks is given in Appendix 4 (page 10 – 12). The testing for the Definitive Workshops for the complexity of the Design Task is done with analysis of the same 3 data-sources.

KEY-COMPONENT C2: DESIGN TEAM

A first result related to team is that it was possible to organize competent practitioners to attend the workshops, although a few remarks should be made here. During the Workshop Series it became clear that the role of the Professional Organizations was essential in advertising the Workshop Series as training for the Permanent Education of the professionals and to manage the registration of objectively evaluated competent practitioners.

A second result is the continued observation in the teams in WS04 and WS05 confirmed that all practitioners made contributions during the design process. Both Architects and Contractors contributed function-types and sub-solutions related to their knowledge-type; object-related or realization-related. However, it was also observed that the contributions within the teams were not always sufficient; in some cases essential realization-related function-types were missing. An explanation is given in the conclusion for WS04 related to the complexity of the task and time-

constraints. The results of the developed Improved Research Analyses Protocol and the developed Video Observation Format, Video Interaction Format and the Morphological Analysis Format show that they are an effective and practical way to answer Research Questions RQ6 and RQ9.

KEY-COMPONENT C3: PRACTICE SETTING

The results of the face-to-face setting during the Workshop Series are positive. Observation of the interaction between the Architects and Contractors shows that a majority of the Architects and Contractors collaborated through interaction using the different media of speech, sketches and through the Morphological Overview during the design process. This outcome is confirmed by the practitioners in the evaluation of the setting. This evaluation was done through the application of a pre-defined questionnaire which had to be filled in twice, once directly after the workshop and again after 6 months via email. Overall, the results of both questionnaires were positive about the workshop setting. The average response for the questionnaires after 6 months was 87% and the average satisfaction rating was 3.4 (out of 5) for the workshop-setting. The overview of these questionnaires is presented in the overview of the questionnaires for WS03 – WS05 in Appendix 13 (Figure 13.1, page 190). In the final conclusion and discussion Chapter the outcomes of the different evaluations with the practitioners will be discussed. With the developed Video Observation Format (VOF) and Video Interaction Format (VIF), interaction could be determined on team level as well as on the individual level. These two Video Formats were adopted for the testing in the Descriptive Study 2.

Two aspects influenced the success of the setting: the organization of the Workshop Series itself and the organization of the observation of the Workshop Series. The most important aspect was to avoid the researcher influencing the practitioners (Gummesson 1991). As mentioned related to the key-component of Team, the Professional Organizations were used to manage the organization of teams as well as part of the setting. For the Workshop Series WS05 the organization of the setting was managed by a collaboration of the TU/e, the Professional Organizations and trained assistants. The trained assistants also helped during the last Workshop Series WS05 for observation purposes and practical aspects. A script was made and used for the organization of the Definitive Workshop and its setting, for the Professional Organizations and for the tasks to be performed by the trained assistants.

KEY-COMPONENT C4: DESIGN SUPPORT TOOL

The result regarding the uptake of the tool is positive; in all different Design Task Settings more than 90% of the teams and practitioners used the Morphological Overview (MO). This shows that the practitioners were not averse to using the tool when they had the choice to use it.

The observations used in the developed Improved Research Analyses Protocol (WS05) showed that the MO was used by the practitioners to exchange and structure their object- and realization-knowledge in a balanced way. There are two important conclusions to be drawn here when viewing setting Y1 and X2. First, on the team level average notated Function-types on team-level (Figure 52, page 118, Total F; Y1 and X2). In average 24% of all notated items was also notated in the MO. With the focus on realization-related contributions in the Design Task Settings were the MO was loose introduced in both group X and Y these contributions were higher compared to the Design Task Setting without the MO. Second result is on the influence of the order of loose introduction of the MO. This shows that the tool did indeed play an important role in the process. In the situation were the MO was loose introduced in the first design task (Group Y) for both object- and realization knowledge fewer contributions were made in the second design task without the MO. In group Y, 92% less realization-related contributions. In group X there is an increase of 72% for contributed realization-knowledge.

A third conclusion is that the contributions of the roofers decreased when the Morphological Overview was introduced in the first Design Task Setting for teams. This might be explained by the fact of two

variables; working together in teams on a Design Task collaboratively and the introduction of a Morphological Overview were difficult to combine for the Contractor, especially within this 'pressure cooker' situation. The order of introduction which was adopted for the testing in the Descriptive Study 2 was to start without the Morphological Overview followed by the Design Task Setting with loose introduction of the Morphological Overview. To determine whether a possible learning effect is taking place in the practitioners, the parallel Design Task Setting should use loose introduction of the Morphological Overview for both design-tasks.

A final yet crucial conclusion can also be drawn here regarding the developed analysis-format. On the basis of the extensive application conducted in this workshop series, it can be concluded that the developed Improved Research Analyses Protocol is a useful and effective tool for observation and analysis. The inclusion of the Video Observation (VOF) and Interaction Format (VIF) and the Morphological Analysis Format (MAF) mean that it was possible to capture the required level of granularity of team interactions. Because of the use of the Improved Research Analyses Protocol and the developed formats the relevant data are analyzed to determine the contributions of the teams and practitioners within the teams and the influence of the Morphological Overview. For that reason the Improved Research Analyses Protocol, the VOF and the VIF are adopted for the testing of the RQ's in the Definitive Collaborative Design Workshop.

OUTCOME 2: THE DEFINITIVE COLLABORATIVE DESIGN WORKSHOP

The second outcome of the Prescriptive Study is derived from the finalized research improvements related to the key-components (Design Task, Collaborative Design Team, Practice Setting, Design Support Tool) which were introduced and developed throughout this research project. These finalized research improvements are tested in the Descriptive Study 2. This workshop the Definitive Collaborative Design Workshop has formats to organize, observe, analyze and evaluate interaction and knowledge exchange in the Practice Setting for Design Teams to work collaboratively on a Design Task with support from a Design Support Tool (the key-components). The Collaborative Design Workshop is presented in 3 parts:

1. The Definitive Collaborative Design Workshop

2. Observation, analyzing and evaluation Formats

3. Improved Research Analyses Protocol

In Descriptive Study 2 the key-components Design Task, Design Team, Practice Setting and the Design Support Tool and finalized research improvements (Observation, analyzing and evaluation Formats and Improved Research Analysis Protocol) are tested. This is done in the Definitive Collaborative Design Workshop.

To analyze the influence of the Morphological Overview (MO) a specific setting had to be designed, based on the previous experience of the BS research group and on literature review and iteratively improved through a series of workshop series (WS03 to WS05). Here, it was important to develop different task conditions, some with the introduction of the MO and some without, in order to evaluate the effect of the use of the MO. This development was guided by the results of the individual Workshop Series in which the practitioners were introduced to the MO. An overview of these different Workshop series is provided below:

WS03: Task 1; without MO (team), Task 2; with MO (team changed)

WS04: Task 1; with MO (individual), Task 2; with MO (team)

WS05: Group X+Y: Task 1; without MO (individual)

Group X: Task 2; without MO (team), Task 3; with MO (team changed)

Group Y: Task 2; with MO (team), Task 3; without MO (team changed)

First, a description of the Collaborative Design Workshop is given (Figure 55, page 126).

1. THE DEFINITIVE COLLABORATIVE DESIGN WORKSHOP

The Collaborative Design Workshop was organized as 'training' for two types of practitioners, designers (Architects) and Contractors (roofers / installers). Professional Organizations played an important role in advertising the Goal of the training as an opportunity for the participants to learn and practice to operate in a collaborative team while working on a complex design task, I.E. roof designs for sustainable buildings. The Workshop comprised of three tasks and was executed over two days with one week between day 1 and day 2.

What follows is a brief explanation of the Collaborative Design Workshop from the experience and findings of the workshop series in the Prescriptive Study. The first point to mention is that because Contractors were expected to have little or no design-experience, the workshop started with an individual design task (Task 1) comparable in complexity with the following design tasks (Task 2 and Task 3). The Goal of task 1 was simply to provide the Contractors with an opportunity to practice design in working on a complex design task. Thus, the results from this initial training session (Task 1) are of no interest to the current discussion. What is of interest are the results of tasks 2 and 3, which were both undertaken with CD teams.

For design task 2 the practitioners were randomly assigned into two groups, X and group Y, with an equal amount of designers and Contractors. Each team within group X and Y consisted of one Architect and one Contractor. For task 2, which also took place on day 1, teams in group X were asked to work on the design-task without the Morphological Overview (X1). The group Y teams, alternatively, were asked to work on the design task after the Morphological Overview had been loosely introduced (Y1). Day 1 ended with presentation of the designs by the teams, which allowed the practitioners and the research to reflect on the process. This was applied with a general reflection after the presentations of the design on the complexity of the task, the collaboration and use of the MO.

Design task three took place on the second workshop day one week later. All of the practitioners remained in the same group as in task 2 (group X or Y), but were assigned to new teams. Teams from group X were introduced to the Morphological Overview for the first time (X2). Essentially, since the teams in group Y had already been introduced to the Morphological Overview in the previous task, the current condition acted as a repeated test of task 2 (Y2). Day two also provided the practitioners with the opportunity to reflect on the workshop by allowing the teams to present and discuss the contributed designs.

In order to monitor the development of the team designs, the various documents produced by the teams were photographed every ten minutes. In addition, three teams in each Design Task Setting were randomly chosen to be video-recorded. These video recordings were used to verify both the findings of the research and the formats of observation and analysis. To aid the management of the workshops, trained assistants were used to handle a number of practical aspects; including managing the observation with a minimum of distortion for the practitioners involved. In order to get direct feedback from the practitioners within the research on a number of aspects of the research, pre-defined questionnaires were administered directly after the workshop to all participants. Finally, in order to determine whether the evaluations of the practitioners remained constant over time, trained assistants conducted interviews with all participants six months after the workshops.

One important finding from WS03-WS05 concerns the effect of the order of introduction of the Morphological Overview to the Contractors. It was discovered that results for Contractors were improved when they had the opportunity to first work on the design without a Morphological Overview and then progress to work on a following task with the Morphological Overview. This finding was incorporated in the Definitive Collaborative Design Workshops for group X.

A second finding from WS03 to WS05 concerns the complexity of the design task and the use of the Morphological Overview. A majority of the practitioners evaluated the design task as complex. While the workshops functioned to allow the research to study collaboration within design teams, it is important to remember that in the minds of the practitioners, the workshops were designed as training sessions. Thus, to provide the practitioners with maximum value from this training, time to evaluate and reflect on the activities was necessary (Kolb 1973, Schön 1987). Therefore the second design task for the teams and the evaluation was organized one week after day 1.

The lay-out for the Definitive Collaborative Design Workshops is shown in Figure 55.

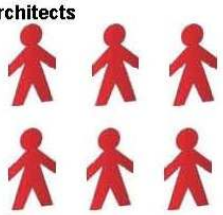
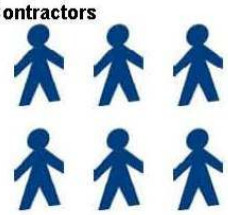
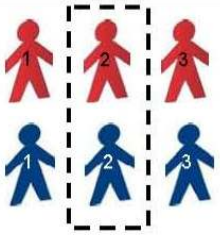
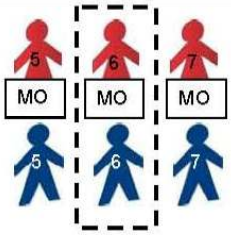
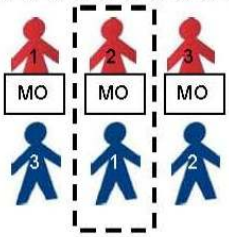
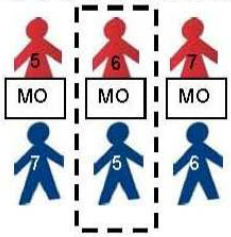
STEPS			**RESULTS**
Design Task 1 - Function-types and Sub-solutions	**Architects**  Individual *without MO*	**Contractors**  Individual *without MO*	**Design Task 1** Function-types and Sub-solutions **Individual *without MO*** Registration
Design Task 2 - Function-types and Sub-solutions > Design - Each team = Architect + Contractor - Presentation + evaluation	 Teams *without MO*: **X1**	 Teams *with MO*: **Y1**	**Design Task 2** Function-types and Sub-solutions + Design **Team *with / without MO*** Registration + Observation
Design Task 3 - One week in between Design Task 2 and 3 > reflection practitioners - Function-types and Sub-solutions > Design - Each team = Architect + Contractor (change teams) - Presentation + evaluation	 Teams *with MO*: **X2**	 Teams *with MO*: **Y2**	**Design Task 3** Function-types and Sub-solutions + Design **Team *with MO*** Registration + Observation + Questionnaire

Figure 55 Definitive Collaborative Design Workshop Lay-out (DWS).

The signed-in practitioners were randomly assigned to two groups; equally number of Architects and Contractors: Group X and group Y. Members which were organized in one group worked in this group for the whole CD Workshop. All teams of Group X and Group Y were given a number related to the design task of the session. Each group consisted of minimal 3 teams. All teams were anonymous related to the names of the practitioners for use of analysis, only their profession is notated (Architect = A, Contractor = C) with a number of subscription. Group X and Y are organized with a pre-defined scheme as shown in Figure 55, for individuals (1 task) and CD-teams (2 tasks) . When organized for

each group X and Y, 3 CD-teams were randomly selected for observation / monitoring by video-recordings. Only the results of the video-recorded CD-teams were observed and analyzed. The participants of these monitored CD-teams for design task 2 were also used for design task 3 but in now participants were changed for this task in the new CD-team.

The comparison for the results of each Research Question concerning the four key-components (Task, Team, Setting and Tool) will be on the average results of the different Design Task Settings for group X and Y and between the different Design Task Settings (X1, X2, Y1 and Y2). This comparison of Design Tasks is as follows:

1. Team-setting without MO (Task 2 NMO) / Group X1 <> Team-setting with MO first time (Task 2 MO1) with team where MO is loosed introduced / Group Y1
2. Team-setting without MO (Task 2 NMO) / Group X1 <> Team-setting with MO first time (Task 3 MO1) / change team / Group X2
3. Team-setting with MO first time (Task 3 MO1) / Group X2 <> Team-setting with MO second time (Task 3 MO2) with team where MO is loosed introduced / Group Y2
4. Team-setting with MO first time (Task 2 MO1) / Group Y1 <> Team-setting with MO second time (Task 3 MO2) with team where MO is loosed introduced / Group Y2

The participants which were part of a group X or Y were part of these groups during the entire workshop. For each Design Task Setting the participants within the Team were changed. This was done for the following reasons. First; to observe and compare the interaction and knowledge exchange within the Collaborative Design setting throughout the steps of the workshop it was necessary to avoid the learning effect of practitioners within one team. Second; to avoid the learning effect of the practitioners within the teams in order to observe and compare the influence of the MO on the interaction and knowledge exchange between practitioners. Third; in the practical situation, comparison of teams would imply matched teams, which could not be organized in this research project and would also not be a situation which does occur; because teams in practice will often change through the project process.

The minimal amount of changing teams related to the Lay-out requires at least 3 teams per Design Task-setting. For the observation of the teams by video-camera therefore, 3 teams of each Design Task Setting are video-recorded. This implies that of each DWS in total 12 teams are video-recorded. Only the results of the teams which were also video-recorded where used as comparable data. This with exception of the data for RQ5, and for the pre-defined questionnaires and interviews after 6 months.

2. OBSERVATION--, ANALYZING- AND EVALUATION-FORMATS

The second result of the Prescriptive Study is the developed formats to observe and analyze related aspects to the key-components (Task, Team, Setting, Tools). These observation and analyzing formats are:

1. The Video Observation Format (VOF)

2. The Video Interaction Format (VIF)

3. The Morphological Analyzing Format (MAF)

4. Evaluation Formats (questionnaires and interviews after 6 months)

3. IMPROVED RESEARCH ANALYSES PROTOCOL

The Improved Research Analyses Protocol in brief can be described as follows:

1. First step: collection of produced documents and collects the notated function-types and sub-solutions. Use the MAF1 and photographs to get acquainted to the data.

2. Second step: confirm the found function-types and related sub-solutions from step 1. This is done by the use of the VOF to determine the *what, how, when* and *who* of the specific communicated function-types referring to the reference list with object- and realization-related function-types.

3. Third step: organizing the VIF, derived from the VOF as a graphical way to observe and analyze interaction between the different types of participants within the teams.

4. Fourth step: combine the data from VOF and VID into the MAF2 for individual teams and MAF3 for all teams within one Design Task Setting to determine and analyze team-contributions of object- and realization-knowledge.

5. Fifth step: combine the data of the VOF and VIF per Design Task Setting and team to determine and analyze the contributions for object- and realization-knowledge on participant-level.

An extended example for WS05 of the use of this Improved Research Analyses Protocol is presented in Appendix 12.2 (Example 3, page 151 – 157).

3.3.7 OVERVIEW DRM-STAGES, THE CORRESPONDING RESEARCH QUESTIONS AND GOALS

In the Prescriptive Study the different aspects related to the four key-components (Design Task, Collaborative Design Team, Practice Setting, Design Support Tool) were developed. This was done by answering the related Research Questions. To answer these Research Questions in the Practice Setting of different Workshops different research improvements were developed. These research improvements are the formats to observe, analyze and evaluate the interaction and knowledge exchange on Workshop-, Team- and Practitioner-level; between Architects and Contractors in each Workshop. The main steps for these formats and the finalized formats are presented in Figure 56, as part of the DRM Overview.

Within the DRM-stage of the Prescriptive Study the development steps are presented of the different Workshops in relationship with the outcomes of these Workshops. The outcomes are twofold. First: related to the specific Research Questions to be answered to define the key-components. Second: the results of the research improvements to reach the Goals. The finalized Research Questions and Goals in the Prescriptive Study are marked in yellow in Figure 56. The different research improvements and the finalized formats are an essential outcome of this Prescriptive Study and necessary to execute the next DRM-stage; the Descriptive Study 2.

	DRM Stage	Research Question(s)		Goals
1	**Research Clarification**	**RQ1**	*What type of knowledge should the competent architect, roofer and installer possess?*	Problem identification+answers RQ1-RQ2
		RQ2	*When and how should this knowledge ideally be exchanged within a Collaborative Design Team?*	Development of RQ3 and RQ4 Hypotheses and Measurable Success Criteria
2	**Descriptive Study 1**	**RQ3**	*What factors hindered the success of the Case Study projects?*	Problem is expressed in practice
		RQ4	*What are the necessary key-components of the Technological Design?*	Key-components identification Development of: RQ 5-6-7-8-9
3	**Prescriptive Study**			Pre-Answers to: RQ 5-6-7-8-9 Research Improvements
	WS01 *Students workshop*			Determine if the setting encourage interaction Determine if Observation Format is suitable
	WS02 *Students workshop*			Development of alternative observation and analysis methods for the effects of use of the (loosely introduced) Morphological Overview Determine the effect of the use of the (loosely introduced) Morphological overview on knowledge exchange
	WS03 *In-company workshop*	**RQ5**	*Were the tasks sufficiently complex to require the collaboration between the practitioners?*	Evaluation of the analyses to determine the complexity of the Design Task; a quick-scan, the Functional Analysis, pre-defined questionnaires
		RQ7	*Did the face-to-face setting provided by the workshop allows collaboration between the practitioners working on the design task?*	Evaluate the use of the developed Quick-scan, the Observation format 2 and Morphological analysis format
	WS04 *Practitioners workshop*	**RQ6**	*Did both types of practitioners succeed in contributing realizations knowledge?*	Evaluate the use of the developed Video Observation Format and the Research Analysis Protocol
		RQ8	*Did loose introduction of the Morphological Overview lead to acceptance of the tool by the practitioners?*	Evaluate the adoption and use of: the Morphological Overview: Quick-scan, Morphological Analysis Format 3 (MAF3) and Pre-defined questionnaires
	WS05 *Practitioners workshop*	**RQ9**	*When used did the Morphological Overview stimulate for the exchange and structuring of knowledge between the practitioners?*	Evaluation of the effect of the use of the Morphological overview Evaluation of the use of: the Video Observation Format (VOF), the Video Interaction Format (VIF) Development and application of the Collaborative Design Workshop lay-out Finalizing of Research improvements
4	**Descriptive Study 2** *Practitioners Workshop*	**Test RQ 5-9**		Answers to: RQ 5-6-7-8-9 Testing the key-components and Research improvements in the Definitive Collaborative Design Verification of the key-components and the analyzing tools: VOF, VIF, MAF3, and Evaluation Formats Evaluation of the Hypotheses and Measurable Success Criteria

Figure 56 DRM-stages with corresponding Research Questions and Goals.

3.4 DESCRIPTIVE STUDY 2

3.4.1 INTRODUCTION

The main Goal of Descriptive Study 2 is to test the so called: Definitive Collaborative Design Workshop (DWS), its key-components, the observation and analysis formats and the improved research analyzing method.

Since many of the assumptions made in the previous stage turned out to be well founded, only minor changes were necessary in Descriptive Study 2. The four key-components of Design Task, Collaborative Team, Practice Setting and Morphological Overview continued to be the central focus. However, two types of changes were made: refinements and reconfigurations to the key-components took place, and the analysis of the output of the Collaborative Design teams was improved by some small modifications of the formats and analyzing-steps. These finalized research improvements will be listed per stage and workshop.

KEY-COMPONENT C1: DESIGN TASK

Although the design tasks themselves underwent no real change in the final stage, the formats used to analyze the tasks were changed somewhat. Essentially, in order to allow other research to apply the Collaborative Design Workshop developed here, the analytical formats needed to be made more efficient. The Video Observation Format and Video Interaction Format in combination with the Morphological Analysis Format was used (see CD Protocol 3.7.2, page 177).

KEY-COMPONENT C2: COLLABORATIVE DESIGN TASK

Only one change relating to team was introduced in this stage. In order to render the assignment of practitioners to teams more transparent, an application coding related to the practitioner-type and Design Task Team was added.

KEY-COMPONENT C3: PRACTICE SETTING

While the workshop setting was used throughout all testing stages of the research project, the precise configuration was modified throughout the Prescriptive stage, leading to the Definitive Collaborative Design Workshop Lay-out applied in Descriptive Study 2. The modifications were made for two main reasons. First: to encourage a greater learning effect on the practitioners, and second: to improve the quality of observation in order to enable a more thorough analysis of the workshop sessions.

In order to try and ensure a smooth running and identical Lay-out of the Definitive Collaborative Design Workshop, a Workshop Script (see Protocol 3.7.1, page 171) was developed and distributed to trained assistants assisting the workshops. Also, additional assistance in organizing and managing the workshops was provided by trained assistants and from the Professional Organizations of the target practitioners.

Some changes were made additional to the evaluation formats (Questionnaires) employed in this stage of the research. The main changes were in the personnel responsible for gathering the feedback and in the medium used to do so. The change was made in an attempt to improve response rates and to reduce possible bias in the responses.

Finally, an evaluation was included during the workshop to gain greater insight in the effect of the Collaborative Design Workshop to find out the practitioners opinion about the workshop experience.

KEY-COMPONENT C4: DESIGN SUPPORT TOOL

The tool did not change in the Definitive Collaborative Design Workshop. However, a format for evaluation of the use of the tool was added in the form of pre-defined interviews with the Practitioners, 6 months after the workshop took place.

In Descriptive Study 2, the final stage of the research project using the DRM framework, testing of the key-components and the finalized research improvements are executed in the Definitive Collaborative Design Workshop. This Definitive Collaborative Design Workshop is the result of the Prescriptive Study. The key-components in Definitive Collaborative Design Workshop are defined as: Design Task, Practice Setting, Collaborative Design Team and Morphological Overview. The testing is done with the use of formats for execution, observation, analyzing and evaluation of the Definitive Collaborative Design Workshop (DWS). These formats are: the Workshop Lay-out, the Video Observation Format (VOF), Video Interaction Format (VIF), the Morphological Analysis Format (MAF), the Evaluation Formats (EF) and the Improved Research Analyses Protocol.

This section is organized as outcomes related to the Definitive Collaborative Design Workshop (DWS) and the key-components. These outcomes are twofold. First: the Results from the application of the formats to verify the key-components in DWS. Second: the answer to Research Question related to this key-component. In this format the outcomes of the testing are presented.

The final result of the research is the Technological Design, presented as a Collaborative Design Workshop, consisting of two parts. Part one: protocol of the Collaborative Design Workshop, part two: protocols for the workshop observation- and result analyses.

3.4.2 TESTING THE DEFINITIVE COLLABORATIVE DESIGN WORKSHOP

The testing of the Definitive Collaborative Design Workshop (DWS) formats is based on the results of Workshop-Series WS03, WS04 and WS05. This testing is conducted by using a number of means. First: the Workshop Setting. Second: the Improved Research Analyses Protocol related to the Research Questions RQ5 to RQ 9 (as concluded in Prescriptive Study) and Third: the observation, analyzing and evaluation formats (VOF, VIF, MAF, EF). It was concluded that the key-components of Task and Team and related Research Questions RQ5 and RQ7 should be relatively easy to answer in the final DWS. Related to the two Goals of the Technological Design this means that the core of the testing is related to the key-components of setting and tool, which are investigated though Research Questions RQ6, RQ8 and RQ9. By testing the key-components and observation- and analyzing formats in the DWS the Research Questions could be answered and the key-components and formats verified. With these tests the two Hypotheses can be confirmed or denied. This testing is applied on the Definitive Collaborative Design Workshop, which was executed twice.

The results of the tests are grouped in two parts. The first part is organized around the testing of the key-components of Task and Team through answering Research Questions RQ5 and RQ7 (3.4.2.1 A and 3.4.2.1. B). The second part of the testing is grouped around the key-components of Setting and Tool and related Research Questions RQ6, RQ8 and RQ9 (3.4.2.1 C and 3.4.2.1. D). For the analysis of RQ6 and the related RQ9, the Improved Research Analyses Protocol is applied.

3.4.2.1 Testing in the Definitive Collaborative Design Workshop (DWS)

The testing of the key-components and related formats to observe, analyzing and evaluate was done in the Definitive Collaborative Design Workshop Setting (DWS), executed twice and each DWS lasting two days. The test of the first Definitive Collaborative Design Workshop (DWS01) took place on 12 (day 1. conference room; Utrecht) and 19 June 2009 (day 2. conference room: university Eindhoven) with 8 Architects and 8 Contractors. The testing of DWS02 took place on 20 (day 1. conference room: Firm in Utrecht) and 27 November 2009 (day 2. conference room: university Eindhoven) with 9 Architects and 9 Contractors.

The practitioners who attended the DWS randomly assigned into 2 groups (group X and Y) and then further divided into teams with an equal number of Architects and Contractors. Task 1 was an individual task. For tasks 2 and 3 teams were again randomly assigned in order that not one participant would work with another participant twice in the same team. This was done to avoid a 'learning effect'. The learning effect would influence the effect of interaction, knowledge exchange and the effectiveness of the Morphological Overview (MO).

Each of the teams consisted of two different practitioners, one Architect and one Contractor. The Lay-out for the Definitive Collaborative Design Workshop is shown in Figure 55 (page 126), for individuals (1 task) and CD-teams (2 tasks). The DWS were managed for group X and Y simultaneously. Participants who were assigned to a specific group would work in this group throughout the whole DWS. From all CD-teams which could be organized from the number of participants which applied to the DWS, per task three CD-teams were randomly selected for observation / monitoring by video-recordings. Only the results of the video-recorded CD-teams were observed and analyzed. The participants of these monitored CD-teams for design task 2 were also used for design task 3 but in now participants were changed for this task in the new CD-team.

To have a minimum of three CD-teams per task and to have the possibility to change the participants for each task within a team at least 12 participants per DWS were necessary. To be sure that this number could be used, more than 12 participants were allowed to apply the DWS, which were all part of the program but only three CD-teams per group and design task are part of the results.

For each DWS a different number of participants applied the workshop. What follows is, first: an overview of the number of participants per DWS, second: the coding of the CD teams per DWS and third: a list of those CD teams which were monitored and analysed per DWS.

1. Overview of number of participants per DWS
DWS 01: 8 Architects, 8 Contractors
DWS 02: 12 Architects, 9 Contractors
Total participants DWS01, DWS02: 37

2. Coding of CD teams per DWS
DWS 01:
- Task 2:
Group X1: B1, B2, B3, B4; Group Y1: B5, B6, B7, B8
- Task 3:
Group X1: C1, C2, C3, C4; Group Y2: C5, C6, C7, C8
DWS 02:
- Task 2:
Group X1: B1, B2, B3; Group Y1: B6, B7, B8, B9, B10, B11
- Task 3:
Group X1: C1, C2, C3; Group Y2: C6, C7, C8, C9, C10, C11
Total teams DWS01, DWS02:

3. CD teams monitored and analysed per DWS
DWS 01:
- Task 2:
Group X1: B1, B2, B3; Group Y1: B5, B6, B7
- Task 3:
Group X1: C1, C2, C3; Group Y2: C5, C6, C7
DWS 02:
- Task 2:
Group X1: B1, B2, B3; Group Y1: B6, B9, B10
- Task 3:
Group X1: C1, C2, C3; Group Y2: (C6), C7, C8
Team C6 in Task 3 in DWS02 was monitored, but the video-recording was damaged, so in the analyses this team could not be used. In total for all design tasks 23 teams were monitored and analysed. The teams from the list above are used in the successive overviews, tables and figures.

The organization of the DWS related to the design tasks is described below:

Day 1.
- Design task 1: individual (Architect, Contractor) (60 min.); function-types and sub-solutions for roof existing building;
- Design task 2: team (Architect, Contractor) (60 min.); function-types and sub-solutions for roof existing building; group X without Morphological Overview (X1) , group Y with Morphological Overview (Y1);split test

Day 2.
- Design task 3: team (Architect, Contractor) (60 min.); function-types and sub-solutions for the roof of an existing building; change teams; group X with Morphological Overview (X2), group Y with Morphological Overview (Y2); change teams

In the following subsection the key-components of the Technological Design are tested in turn with reference to the relevant Research Questions. The order in which the key-components are addressed is as follows Design Task (RQ5), Practice Setting (RQ7), Collaborative Design Team (RQ6) and Morphological Overview (RQ8, RQ9). The outcomes for each key-component are organized in the same way. First, a short introduction is given to each relevant Research Question, followed by a description of the results from the application of the formats used to verify the specific key-components. Finally the answer(s) to the related Research Question(s). In Appendix 12, for each Research Question, an example of the analysis of a representative team is presented. In Chapter 4 the outcomes will be discussed in more detail.

3.4.2.1 C1 Design Task

The first key-component of the Technological Design is the Design Task, which is related to RQ5. The chosen design tasks for the Definitive Collaborative Design Workshop were developed and initially tested in the Prescriptive Study in order to determine that they were sufficiently complex to use the Definitive Collaborative Design Workshop. Three different tasks from the Prescriptive Study were used; two of these were part of the Design Tasks for the teams (Task 2 and Task 3). All design-tasks that were available for the practitioners were documented with the background documents and are part of the Appendix 2. In this paragraph the three views are used as they were developed in the Prescriptive Study for Workshop Series 3 (WS03).

The Design Tasks presented to the teams need to be sufficiently complex to encourage the collaboration of the team members. To evaluate whether the used design tasks where complex

enough to encourage the professional practitioners to collaborate, the 3-analyes developed in the Prescriptive Study was used (page 90-93)..

1. Analysis 1: results of the quick scan

To have a first impression of the variety of used type of documentation and used function-types the quick scan was used. This scan was done by counting by hand the used types of documentation from the different Design Teams related to a Design Task. The used documents in the Design process were coded by the participants. Each produced document could contain one or more sketches or MO's, each sketch or MO was counted related to the practitioner-type (Architect, Contractor) and type of communication (sketch, MO). In all teams a variety of media were used during the design-process by Architect and Contractor to contribute and organize their knowledge. These media included sketches, schemas, notations and the introduced Morphological Overview which were used in various ways. Figure 57 shows representative examples of these produced documents. What can also be seen in this Figure is a good mix of contributions, from more concept-based contributions of object-knowledge to those to detailing with different examples of notated realization knowledge. There were no significant differences in the used mediums between DWS01 and DWS02.

Figure 57 Impression of different types of notations in produced documents for DWS01 and DWS02.

The overview presented in Figure 58, page 135, of the communication-types used by the practitioners in the different settings gives a first impression of the variety of documents which were used for all design tasks and all design teams in DWS01 and DWS02. The table gives the overview of the amount of documents with sketches and the use of the Morphological Overview (MO) which were determined from the delivered documents by the design teams after the workshop. In Appendix 6 (Figure 6.1, page 22), the total overview of this amount of used documents per Design Task en Design Team is presented. Although the Architect is the dominant practitioner related to all produced documents (Sketch and MO: 75%), the Contractors use notations to put forward their own items related to the Design Task (Sketch and MO: 25%). The table also shows that of all produced documents 26% (18 +

12 out of 87 + 29 = 30 out of 116) were MO's and that the Contractors contributed 40% (12 out of 30) of these MO's.

The overview in Appendix 6 (Figure 6.1, page 22) gives a more detailed picture. In all teams documents were made. In all teams (23) the Architects produced one or more sketches (60% of all produced documents). Of the Contractors 6 out of 23 produced no documents at all. In all other teams the Contractors produced 1 or more documents with sketches (15% of all produced documents). This is only a first indication in variety of used communication-types. The next view will provide another comparison on the variety of produced items in these documents.

DWS TEAM	HOW	DWS TOTAL	
		DOCUMENTS	PERCENTAGE
ARCHITECT	SKETCH	69	60%
	MO	18	15%
TOTAL ARCHITECT		**87**	**75%**
CONTRACTOR	SKETCH	17	15%
	MO	12	10%
TOTAL CONTRACTOR		**29**	**25%**

Figure 58 DWS Total: Overview of amount and percentage of used type of communication (sketches / notations, MO) by different practitioners.

2. Analysis 2: results of the Morphological Analysis 1

For the second analysis the Functional Analysis is used to determine the variety of notated function-types as an indication of how the complexity was handled by the teams. To provide the results, the overview from the Morphological Analysis Format 1 (MAF 1) is used for each Design Task Setting with a quick-scan from the produced documents and notated in blue. In Figure 59 these items are notated in blue. These MAF1 overviews are used to determine how many of the notated function-types are also present in the reference-list. In Appendix 10 the overviews of the MAF1 as part of MAF3 are presented. Figure 59 gives an example of a MAF 1 for one representative Design Task Setting: Task 3 for DWS01 (Group Y2, Teams C5, C6 and C7). In the green box: realization-knowledge.

DWS 01 Teams: C5, C6, C7 MO2 Task: 3 / Y2								Total sub-solutions
1. Rain / water proof	Vegetation roof (C5)	Grey water (C5-MO, C6-MO)						2
2. Temperature proof								
3. Ventilation	CO2 / Natural ventilation (C5-MO)	WTW / Natural ventilation (C5-MO)	Balanced ventilation / WTW / humidity (C5-MO)	Roof cooling ventilation (C5-MO)	Mechanical ventilation + RV (C5-MO)	Movable ventilation panels (C6)		6
4. Maintenance	Frequency (C6.1-MO)	Accessibility (C6.2-MO)	3-D / Complex (C6-MO)	Panel-engines (C6-MO)				4
5. Safety (C5-MO)								
6. Heating & Cooling	CO2 / Natural cooling (C5-MO)	Heat pump (C5-MO)	Air roof ventilation (C5-MO)	Passive concrete buffering (C5-MO)				4
7. Sustainable energy generation	PV rotating / movable panels (C7)	Grey water (C5-MO)	Wind-mill (C5-MO)	PV-panels / Water cooling / buffering (C5-MO, C6)	PVT-panels (C5-MO, C6-MO)	Sun gutters (C7)		6
8. Construct & Build								
9. Comfort & Health								
10. Accessibility								
11. Operational								
SUB-TOTAL REALIZATION F: 6 (50%) REALIZATION F IN MO: 6								SUB-TOTAL REALIZATION SS: 22 (56%) REALIZATION SS IN MO: 18
12.Light / sun-use & Protection	Passive light use, regulation (C5-MO, C6-MO)	All dimensional, light play (C5-MO, C6-MO)	Electric light (C5-MO, C6-MO)	Roof lights (C5-MO)	Pergola's, shadow system, inside + outside (C6.1 / 2-MO)	Mirror panels in glass (C6-MO)	UV-light quality (C6.2)	8
12.Light / sun-use & Protection	Textile / tent-construction (C7)							
13.Functions for building & roof	Protecting against climate (C5-MO)	Roof-landscape (C6-MO)						2
14. Orientation & Sight (C5)								
15. Construction	Light weight construction / steel (C7)	Permanent / light construction (C6-MO)	Dynamic / movable (C6-MO)					3
16. Costs & Finance & Benefit	Return on investment (C6)							1
17. Architecture	Spatial quality (C6-MO)	Integrality (C6-MO)	Play of light (C6-MO)					3
18. Sustainability								
19. Building Physics								
20. Fire protection								
21. Utilities								
22. Shape								
23. Material								
24. Users								
25. Flexibility								
SUB-TOTAL OBJECT F: 6 (50%) OBJECT F IN MO: 4								SUB-TOTAL OBJECT SS: 17 (44%) OBJECT SS IN MO: 13
TOTAL F: 12 TOTAL F IN MO: 10 IN MO (83%)								TOTAL SS: 39 TOTAL SS IN MO: 31 IN MO (79%)

Figure 59 Morphological Analysis Format 1 (MAF1); DWS01 Task 3 Group Y2 (MO2), Teams C5, C6, C7.

For the representative Design Task Setting Task 3 DWS01 group Y2 (MO2) the following results were found: 12 out of 25 reference function-types (F) and 39 related sub-solutions (SS) were notated by the teams. Of the 12 notated function-types there was an equal notation of object- and realization-knowledge. For the 39 notated sub-solutions 22 (56%) were realization-related and 17 (44%) object-related. This first view shows that there is a variety of function-types and sub-solutions notated, although not the variety expected, which should be more than 50% of the function-types from the reference-list notated. These separate overviews were combined into a total overview for all Design Task Settings in order to determine the global result for all Design Task Settings. In Appendix 10 all overviews of all design teams are presented, where in these overviews the amount of notated items in the MAF 1 is in blue as part of the total amount, notated in black. .The total overview from this MAF1 of all Design Task Settings for DWS01 and DWS02, presented in one total overview as average results, is presented in Figure 60.

The overview provided in Figure 60 provides a breakdown of all of the average notated function-types and sub-solutions all of the different Design Task Settings of DWS01 and DWS02. The first result of interest is to determine the extent to which the notated items represent the items on the reference-list of function-types (25 items). For the quick-scan the overall view for all teams in one Design Task Setting is used. This first view shows that in average for DWS01 and DWS02 the lowest result is in group X2 / DWS01 with 9 items of the 25 items of the reference-list notated and the highest result in

group Y1 / DWS01 with 20 items notated. Overall about 50% of the function-types were identified through the MAF1 analysis.

DWS	SOLUTION- TYPE	TASK 2 NMO / X1 B1, B2, B3 (6)	TASK 2 MO1 / Y1 B5, B6, B7, B9, B10 (6)	TASK 3 MO1 / X2 C1, C2, C3 (6)	TASK 3 MO2 / Y2 C5, C6, C7, C8 (5)
DWS 01	FUNCTION-TYPES	12	20	9	11
	SUB-SOLUTIONS	29	81	41	39
DWS 02	FUNCTION-TYPES	12	10	18	16
	SUB-SOLUTIONS	31	53	58	60

Figure 60 Overview from Morphological Analysis 1: notated function-types and sub-solutions per Design Task Setting.

The second result of interest is the average amount of notated function-types and sub-solutions. Because there is no reference about what could be the 'highest' amount when a task is complex, an indication could only be an increase of the amount as the task settings progress through the workshop. For the used function-types the two DWS' give a contrary tendency. In DWS01 in each following Design Task Setting there is a decrease of found function-types and in DWS02 in each following Design Task Setting an increase can be identified. For the sub-solutions the results are clearer. With exception of DWS01 group Y, in all other Design Task Settings there is an increase of notated sub-solutions in the succeeding design task. Although the total result is not evident, this increase in the amount of sub-solutions is a conservative indication of the teams' response to the *complexity* of the task.

3. Analysis 3: results of the Pre-defined questionnaires

For the execution of the third analysis the results of one question of the questionnaire administered directly after the workshops are used. The results of the average ratings in DWS01 and DWS02 are shown in Figure 61. In this Figure A = Architects, C = Contractors. A total overview of the results can be found in Appendix 14 (Figure 14.1, page 191). The following rating where introduced to the practitioners and the score used for the researcher between brackets, 1: poor (2), 2: insufficient (4), 3: sufficient (6), 4: good (8) and 5: very good (10).

DWST TOTAL **Rating 1-5**	**Q2** How did you experience the complexity of the design-task
DWS 01 A average	3,6
DWS 02 A average	3,8
DWS 01 C average	3,3
DWS 02 C average	4,0
AVERAGE TOTAL	**3,6**

Figure 61 Average outcome for Questionnaire DWS Total (fragment): results for question complexity design-task.

The table provides the average results of both types of practitioners for DWS01 and DWS02. Aside from the fact that all participants clearly considered the task to be complex, two results are worth pointing out. First, the ratings of complexity off the design-task of both the Architects and the Contractors are higher for DWS02 than in DWS01. Second, the rating of the complexity of the design-

tasks is more or less the same in average responses of the Contractors than in those of the Architects. This is an indication that the design tasks are complex for both types of practitioners.

4. Answer for RQ5

What motivated RQ5 were the following assumptions in the research project. First, that the more complex the task the more need there is for collaboration. Second, that any approach seeking to study collaboration must provide the collaborative teams with sufficiently complex tasks which, all other things being equal can only be satisfactorily completed through effective collaboration. The testing of the complexity of the tasks was conducted via analysis of three different analyses. Analysis one of the team documents, showed that the teams exploited a wide variety of media to contribute their knowledge. In analysis two, the Morphological Analysis was used to capture all of the notated function-types and sub-solutions notated in the various team documents. This analysis conformed that a wide variety of function-types and sub-solutions had been contributed by the teams and that a good mix of object related and realization related items were present. The third analysis involved getting direct feedback from the participants on their rating of the complexity of the design tasks. Both Architects and Contractors clearly rated the task as complex. The results of all of the views add up to a clear and consistent answer to the question.

RQ5 *Were the tasks sufficiently complex to require collaboration between the practitioners?*

A RQ5 To solve complex Design Tasks, different types of knowledge are needed which have to been put forward and developed by different types of practitioners. This knowledge is discussed and notated as function-types and related sub-solutions to get insight into the complexity and to generate possible solutions in collaboration. Through the analyses within the research project the different types of notations, the used amount of function-types and sub-solutions and personal questionnaires show that the Collaborative Design Workshop is a productive setting for the different practitioners to work on such complex design tasks.

3.4.2.1 C2 Practice Setting

The Goal of answering RQ7 is to confirm that the produced documents were actually the result of collaboration, defined as interaction, between the different practitioners in the teams and not simply the result of one team member. To make this determination, a further step in the analysis was taken. To investigate if there was interaction between Architect and Contractor three types of analyses were used: Analysis of Photographs, Analysis of Video Recordings and MAF 3 Analysis. For the interaction three main types of communication were observed: speech, notations on paper in sketches, schemas and notes and notations in the Morphological Overview. An example for the analyses related to the Practice Setting is presented in Appendix 12.3 (Example 4, page 158 – 166)

1. Analysis of photographs

This first step in answering the question involves performing a quick scan of the photographs of the different teams in the different design-task sessions. What could be viewed from this analysis of the photographs was, as in RQ5, that in most of the teams the different practitioners made notations on various types of documents and that some documents included notations from both practitioners. Most of the practitioners took an active role in the discussion and development of the design-task.

The examples of teams in Figure 62 show situations demonstrating discussion and interaction between the different types of practitioners during the design-task sessions.

Figure 62 Different working situations in DWS01 and DWS02.

While this photographic evidence provides useful insight into the collaboration between team members, these insights merely represent a fragmented impression of teamwork within the total duration of the design-task of 60 minutes. Thus, it was important to seek to verify the impressions from the photographs via other means. This initial verification of team interaction was sought on the basis of the observations from the trained assistants in the workshops.

The trained assistants were each assigned a design team and were asked to record their impressions of interaction within the team throughout the workshop. Once the workshop had been completed, the observers and the researcher compiled the individual impressions into a general evaluation of interaction.

The result of this general evaluation is that there was a clear pattern of interaction about the design-task between the practitioners. However, two main remarks of the trained assistants are important to note. In the early stages of the design-task sessions many teams discussed general subjects as well as their own practical experience and background. Strictly speaking, while this interaction may have established common ground between the team members, it was not considered relevant interaction in the research project since it was not task related. The second point worthy of mention is that even though interaction was identified in all teams, the intensiveness of interaction varied per team. In some teams, the Architect was seen to dominate the process.

2. Analysis of Video Recordings

The way to identify whether the face-to-face setting provided by the workshop facilitated collaboration between the practitioners working on the design task, was to video-record the sessions for later analysis. For the analyses of video recordings the Video Observation Format (VOF) and Video Interaction Format (VIF) (see 3.7.2; protocol III A, page 182 and protocol III B, page 184) were used.

The above formats were used to provide a record of the task based communicative exchanges within the teams. The focus here was on identifying the function-types and related sub-solutions that were discussed and notated by the teams in any of the communication-types that they used: speech, sketches, written notes and recording in the Morphological Overview (MO). The criterion for productive collaboration was a good variety of contributed object and realization related function-types and sub-solutions. Due to the expected knowledge distribution in the teams, a good mix of object and realization knowledge would provide an indirect indication that each member of the team had successfully managed to contribute to the task.

Three aspects were analyzed related to interaction within Design Teams:
1 Interaction-type Processed and Not Processed (Figure 63)
On the level of interaction in the Design Teams the first analysis is to determine whether there is interaction or not.
2. When Processed: Communication-types (Figure 64 and 65):

Important is if the Architect and especially the Contractor are able to give input (function-types and sub-solutions) to the discussion about the Design Task through the use of communication-types: Talk, Sketch and MO.
3 When Processed: Interaction-types (Figure 66.1 and 66.2):
Additionally to the use of communication-types the interaction has to be judged on the interaction. This implies that both Architect and Contractor send and receive items (function-types and sub-solutions) about the Design Task.

These results are derived from the transcription of the VIF's of the individual Design Teams. The VIF's are presented in Appendix 7 (page 23 – 47). All steps of this transcription which lead to the results for the three aspects as mentioned are presented in Appendix 8; the Interaction Analysis (page 48 – 83).

During each design-task session 3 teams were video-recorded. The teams to be monitored were chosen randomly by the following schema, related to the Lay-out schema in Figure 55 (page 126). Each practitioner was given a code-number related to type of practitioner and order of subscription; Architect (A*n*) and Contractor (C*n*). Half of the group of Architects and Contractors were assigned to group X and the other half to group Y. For each Design Task the members of the specific group were organized in Design Teams with a coding (page 132) and a coded Architect (A) and Contractor (C) (e.g. Team B1; practitioners A1 and C1) For each new Design Task, teams were changed with practitioners from the same group (e.g. Team C1; A1 and C3).

Per DWS, there are 4 Design Task Settings for each team, of which 12 teams were video recorded (3 teams per Design Task Setting of 1 hour), equaling a total of 24 recorded team sessions for DWS01 and DWS02.

Related to each aspect of interaction the results are presented in the order as mentioned above.

1 Interaction-type Processed and Not Processed
The overview as presented in Figure 63 gives insight into the percentages of Processed and Not Processed communication- and interaction-types as the average of the used amounts of these types by Architect and Contractor. Processed are those items (function-types and sub-solutions) which send or received and explicitly notated in Sketch and MO. Not Processed are the items which were discussed within the teams, but were not explicitly notated through this discussion by the Design Team. The grey boxes in the overviews for X1 are used to explicate the situation were the MO is not used.

PARTICPANT TYPE	COMMUNICATION-TYPE	TASK 2 NMO/X1 B1, B2, B3 (6)		TASK 2 MO1 / Y1 B5, B6, B7, B9, B10 (6)		TASK 3 MO1 / X2 C1, C2, C3 (6)		TASK 3 MO2 / Y2 C5, C6, C7, C8 (5)	
		PROCESSED	NOT PROCESSED	PROCESSED	NOT PROCESSED	PROCESSED	NOT PROCESSED	PROCESSED	NOT PROCESSED
ARCHITECT	TALK	24%	13%	24%	16%	19%	15%	19%	15%
	SKETCH	29%		11%		13%		19%	
	MO	0%		14%		6%		10%	
	TOTAL A	**53%**	**13%**	**49%**	**16%**	**38%**	**15%**	**48%**	**15%**
CONTRACTOR	TALK	16%	12%	11%	18%	17%	17%	14%	18%
	SKETCH	6%		1%		8%		3%	
	MO	0%		5%		5%		2%	
	TOTAL C	**22%**	**12%**	**17%**	**18%**	**30%**	**17%**	**19%**	**18%**
GENERAL PROCESSED / NOT		75%	25%	66%	34%	68%	32%	67%	33%

Figure 63 Overview DWS Total (DWS01 and DWS02); Processed or Not Processed; percentage of average number of interaction and communication-types (Talk, Sketch, MO).

One of the aims of the Collaborative Design Workshop (DWS) is to stimulate interaction, so when the results show an increase of Processed interaction during the DWS as a comparison of the successive Design Tasks this gives a positive indication for interaction.

The first comparison is the balance between Processed (left column) and Not Processed (right column) items for the Workshop, represented by the results in average percentages in the bottom row of Figure 63. All items Processed and Not Processed in one Design Task Setting represent 100%. The comparison between Design Task X1 (without loose introduction of the MO) with the other Design Tasks show clearly that in X1, 75% of the items are processed, which is the highest score related to Y1, X2 and Y2. The second score is for group X2 where 68% of the items are processed. Although this is a decrease compared to X1 it is a better score compared to group Y. In group Y1 there is a score of 66% of processed items which increase with 1%, to 67% in group Y2. All over the percentage of processed items are more than 50% of all used items, although in all groups X and Y there is a decrease of processed items in the successive Design Task. The lowest score is in group Y, in Y2 were the MO is introduced for the second time. For interaction within the Workshop this is a negative tendency.

A second comparison relates to the balance of interaction in processed items between Architect and Contractor (Total A; Architect, Total C; Contractor in Figure 63, page 140). In interaction between Architect and Contractor it is positive when there is a balance in processed items for both practitioner-types. This gives the following results. In group X1 the Contractors processed about a half (22%) compared to the Architects (53%) where in group X2 were there is a balanced situation between Architects (38%) and Contractors (30%). In group Y1 the Contractors (17%) process a third of the items compared to the Architects (49%). In group Y2 there is a slight increase for the contributions of the Contractors (19%); about two-fifth of items compared to the Architects. Group X shows a clear increase in balance between Contractors and Architects were in group Y there is only a slight progress.

Third comparison from this overview which can give an indication of positive interaction is an increase of processed items by the Contractors. Partly this is visible in the former view, but more precise it must be indicated by an increase in the successive Design Tasks. Also for this view group X is most positive; in group X1 average 17% was processed by Contractors with an increase to 30% processed in group X2. Group Y gives a less positive view; only 2% increase.

A special comparison is related to the positive processed use of the MO by Architects and Contractors during the Workshop. The MO should facilitate especially the Contractor by processing the specific realization knowledge. The table in Figure 61 shows the processed MO by Contractors on the horizontal row MO. Overall the Design Task Setting of group Y1 is most positive: here 19% (Architects: 14%, Contractors: 5%) of all items are processed via the MO, compared to 11% in group X2 and 12% in group Y2. The highest score is for Architects in all groups with the highest score of 14% in group Y1 where the MO is introduced for the first time with a decrease to 10% in group Y2. The lowest score for Architects is in group X2; 6%. The best score for the Contractors is in both group Y1 and X2; 5%. In group Y also the Contractors have a lower score in the successive Design Task group Y2; 2%.

2. When Processed: Communication-types.
Important is if the Architect and especially the Contractor are able to give input (function-types and sub-solutions) to the discussion about the Design Task through the use of communication-types: Talk, Sketch and MO. The Interaction Overviews in Figure 64 and Figure 65 show the results related to this aspect. In these overviews the percentages are presented of the average notated function-types and sub-solutions through speech, sketches and in the MO. In the overviews for each Design Task, all notated function-types and sub-solutions in one Design Task represent 100%. Interaction Overview Figure 64 represents all Design Task Settings and Figure 65 gives an overview for comparison between Design Task X1, without MO and the average of the Design Tasks were the MO is loose introduced (Y1, X2, Y2). In Figure 64, in brackets in DWS Total Task, the number of teams which were monitored. In DWS02, Team 6 in group Y2 could not be monitored because the video-recording for

this Design Team was damaged. Therefore only 5 teams in Y2 are monitored compared with 6 teams in the other groups. The grey boxes in the overviews for X1 are used to explicate the situation were the MO is not used.

DWS TEAM	HOW	DWS TOTAL TASK 2 NMO / X1 / TEAM B1, B2, B3 (6)		DWS TOTAL TASK 2 / MO1 / Y1 / TEAM B5, B6, B7, B9, B10 (6)		DWS TOTAL TASK 3 MO1 / X2 / TEAM C1, C2, C3 (6)		DWS TOTAL TASK 3 MO2 / Y2 / TEAM C5, C6, C7, C8 (5)	
		AVERAGE F	AVERAGE SS	AVERAGE F	AVERAGE SS	AVERAGE F	AVERAGE SS	AVERAGE F	AVERAGE SS
ARCHITECT	TALK	39%	30%	46%	34%	32%	27%	30%	29%
	SKETCH	16%	44%	13%	18%	8%	22%	12%	33%
	MO			16%	23%	12%	8%	28%	10%
AVERAGE ARCHITECT		**55%**	**74%**	**75%**	**75%**	**52%**	**57%**	**70%**	**72%**
CONTRACTOR	TALK	37%	19%	20%	16%	32%	23%	27%	20%
	SKETCH	8%	7%	0%	2%	12%	12%	1%	5%
	MO			5%	7%	4%	8%	2%	3%
AVERAGE CONTRACTOR		**45%**	**26%**	**25%**	**25%**	**48%**	**43%**	**30%**	**28%**

Figure 64 Interaction Overview Communication-types per Design Task Setting

DWS TEAM	HOW	DWS TOTAL / NMO / X1		DWS TOTAL / MO / Y1, X2, Y2	
		AVERAGE F	AVERAGE SS	AVERAGE F	AVERAGE SS
ARCHITECT	TALK	39%	30%	36%	30%
	SKETCH	16%	44%	11%	24%
	MO			19%	14%
AVERAGE ARCHITECT		**55%**	**74%**	**66%**	**68%**
CONTRACTOR	TALK	37%	19%	26%	20%
	SKETCH	8%	7%	4%	6%
	MO			4%	6%
AVERAGE CONTRACTOR		**45%**	**26%**	**34%**	**32%**

Figure 65 Interaction Overview Communication-types average, per Design Task Setting

When comparing interaction between Architects and Contractors, related to these tables in Figure 64 and 65, it is important to keep in mind that because of his educational background the Architect is expected to have more skills related to notate explicitly function-types and sub-solutions compared to the Contractor. The first comparison based on Figure 64 is for the different Design Task Settings. The second comparison is between the setting without the MO and the settings with the use of the MO as presented in Figure 65.

What is of importance for interaction is, first; if there is a balance in the processed function-types and sub-solutions of Architects and Contractors, second; if there is an increase of processed items by Contractors in this balance for the successive Design Task and third; if there is a positive influence related to the Design Task were the MO is loose introduced. These interaction aspects are related to the different comparisons of Figure 64 and subsequent Figure 65.

Comparison Figure 64.

Related to the first indication of the balance in processed items the following results can be viewed; there is a clear difference between group X and Y (see Figure 64; Average Architect). Where in group Y the Architects process between 70% and 75% of both function-types and sub-solutions there is a more balanced situation in group X. In group X1, without introduction of the MO, there is a balance for processed function-types (Architect: 55%, Contractor 45%) but a misbalance related to processed sub-solutions (Architect: 74%, Contractor: 26%). In group X2 for both function-types and sub-solutions there is a balanced picture. For function-types 52% is communicated by the Architect and 48% by the Contractor. Architects communicated 57% of the sub-solutions and 43% was communicated by Contractors. This is a clear indication that the step by step approach within group X is more positive for interaction compared to group Y.

When analyzed more in detail, in average in all Design Tasks the processed items through speech are the highest compared to sketch and MO. The most balanced situations are in group X1, X2 and Y2, were there is a negative situation in group Y1; here the Contractors processed half of the items compared to Architects. Related to the use of sketches group Y1 is also the most negative, here the Contractors processed no function-types and the lowest percentage processed sub-solutions. Group X1 and Y2 give more or less the same picture, were group X2 (Sketch, Contractors: 12%) is most positive and with an increase for both processed function-types and sub-solutions compared to group X1.

Related to the processed items through the MO the same picture as for speech emerges. Only in group Y1 the Contractors process a higher percentage of function-types (5%), a third of the percentage processed by the Architects (16%). For the processed sub-solutions both Architects and Contractors process 8% through the MO in group X2. Although in total for Architects and Contractors in group Y1 (21% function-types, 30% sub-solutions) has the highest score for processed items through the MO compared to X2 (16% function-types, 16% sub-solutions) and Y2 (30% function-types, 13% sub-solutions) this is also the group which is less in balance in interaction. For the use of the MO related to interaction these results give an indication that it is used in interaction and knowledge exchange in all Design Task Settings, especially in those settings where the MO is first introduced.

Comparison Figure 65.

In Figure 65 the situation with and without the loose introduction of the MO is viewed. This table gives an overview for the processed function-types and sub-solutions in these two different settings: X1 without loose introduction of the MO and the average for the groups X2, Y1 and Y2 where the MO was loose introduced. When viewing the use of function-types, there is a positive indication for Architects (an increase of 11%) but negative for Contractors (a decrease of 11%) and a contrary tendency related to the processed sub-solutions. For sub-solutions there is a decrease of 6% for Architects and an increase of 6% for Contractors. This gives an indication for the Contractors that when the MO is used related to function-types notated more sub-solutions can be generated compared with the situation when the MO is not loose introduced. Related to the communication-type in sketches and MO, the Architects process about twice more function-types (16% compared 30%), but less sub-solutions (44% compared 38%). For Contractors there is a slight positive tendency for processed items through sketches and MO; a status quo for function-types (8%) and an increase of 5% for sub-solutions (7% compared 12%).

3. When Processed: Interaction-types:
A third analysis on interaction can be related to the aspects of ‘comparable’ and effectiveness in interaction between Architect and Contractor. These two aspects are presented in Figure 66.1 for function-types and in Figure 66.2 for sub-solutions.

The comparisons of interaction concerning function types and sub-solutions need to be made as follows: To indicate the similarity of interaction between contractor and architect the diagonal arrows are used. To indicate effectiveness of interaction the vertical arrows are used. In Figures 66.1 and 66.2 these arrows are shown.

The percentages in the setting the diagonal arrow point at, indicates the sending and receiving of function-types and sub-solutions by Contractor and Architect. In a positive situation the percentages on the diagonal axis are similar; the interaction between Contractor and Architect is at the same level. Both are sending and receiving in an equal manner. The extent to which this interaction is similar is presented by the factors in the row in the table (Figures 66.1 and 66.2) named: ‘comparable’. The most positive situation is expressed when the factor in the row ‘comparable’ is 1,0.

The vertical arrow in Figures 66.1 and 66.2 expresses the effectiveness of send and received function-types and sub-solutions. Here the most positive situation is when all *sent* items are *received* by the other practitioner. This implies an equal percentage for both. So: the *sent* percentage of the Architect compared to the *received* percentage of the Contractor in the left column, or the other way around in the right column. The effectiveness of the interaction is highest if the factor in the row 'effectiveness' of Figures 66.1 and 66.2 is 1,0.

DWS TOTAL	TASK 2 NMO / XI FUNCTION-TYPES			TASK 2 MO1 / YI FUNCTION-TYPES			TASK 3 MO1 / XII FUNCTION-TYPES			TASK 3 MO2 / YII FUNCTION-TYPES		
	↓	↑	TOTAL F	↓	↑	TOTAL F	↓	↑	TOTAL F	↓	↑	TOTAL F
ARCHITECT	40%	15%	28%	62%	13%	75%	44%	8%	52%	50%	20%	70%
CONTRACTOR	14%	31%	23%	9%	16%	25%	6%	42%	48%	2%	28%	30%
COMPARABLE	0,93	0,78		0,69	0,26		0,75	0,95		0,10	0,56	
EFFECTIVENESS	0,35	0,48		0,15	0,81		0,14	0,19		0,04	0,71	

Figure 66.1 Overview for all DWS and Design Tasks; percentages of average processed (speech, sketch, MO) function-types (F).

DWS TOTAL	TASK 2 NMO / X1 SUB-SOLUTIONS			TASK 2 MO1 / Y1 SUB-SOLUTIONS			TASK 3 MO1 / X2 SUB-SOLUTIONS			TASK 3 MO2 / Y2 SUB-SOLUTIONS		
	↓	↑	TOTAL SS	↓	↑	TOTAL SS	↓	↑	TOTAL SS	↓	↑	TOTAL SS
ARCHITECT	59%	15%	74%	61%	14%	75%	46%	11%	57%	60%	12%	72%
CONTRACTOR	4%	22%	26%	6%	19%	25%	3%	40%	43%	4%	24%	28%
COMPARABLE	0,27	0,37		0,43	0,31		0,27	0,87		0,33	0,40	
EFFECTIVENESS	0,07	0,68		0,10	0,74		0,06	0,28		0,06	0,50	

Figure 66.2 Overview for all DWS and Design Tasks; percentages of average processed (speech, sketch, MO) sub-solutions (SS).

Related if there is a comparable situation between sent and received items the yellow highlighted items in Figure 66.1 and Figure 63.2 show a not comparable situation; the situation were the difference in sent and received items is not similar. An example of this situation can be viewed in Figure 66.1 in group Y2 for received and send function-types; 50% send by Architects and 28% by Contractors. For this situation the comparable-factor is 0,56 for received processed items, 2% received from the Architects by the Contractors and 20% received from the Contractors by Architects; the comparable-factor is 0,10. Compared to group X2 were 44% was send by Architects and 42% by Contractors, with a comparable-factor of 0,95. Situation for received in group X2: 6% received by Contractors and 8% by Architects, a comparable-factor of 0,75. For the situation in sent and received sub-solutions (see Figure 66.2) in most Design Task Settings a non-comparable situation can be viewed, except for the sent sub-solutions by Architects and Contractors in group X2 (Architects: 46%, Contractors: 40%; comparable-factor 0,87).

Overall comparing the Design Task Settings for similarity in interaction of function-types group X (X1 and X2) shows a better result compared to group Y (Y1 and Y2). For the comparable situations in interaction of sub-solutions group Y shows a slight contrary tendency for sent (Y1: 0,31, Y2: 0,40) and received. (Y1: 0,43, Y2: 0,33). In group X there is a comparable situation for send sub-solutions (X1 and X2: 0,27) and a positive tendency for received sub-solutions (X1: 0,37, X2: 0,87). The overall picture shows the most balanced situation in group X2 for both function-types and sub-solutions and a positive tendency towards X1 in contrast with group Y.

A second way to analyze these tables in Figures 66.1 and 66.2 is to look at the effectiveness of sent and received items. The most optimum result in effectiveness is that all send items are received by the other participant. This implies a more or less equal percentage in a column for Architect and Contractor (vertical black arrow). For function-types (Figure 66.1) we can view that the most optimum situation is in group Y for the Contractor in both Y1 and Y2. In Y1 the Contractor in average sent 16% of the function-types of which 13% was received by the Architect. effectiveness-factor is 0,81. In Y2 in average 20% of the send 28% function-types by the Contractor was received by the Architect;

effectiveness-factor of 0,71. Comparing the use of sub-solutions in Figure 66.2 shows a more or less same picture; overall most of the sent sub-solutions are processed by the sender and a lower percentage of the send sub-solutions is received and processed by the receiver. When sent by the Contractors the picture varies. In Design Task Setting X2, although the Contractors sent the most sub-solutions compared to other Design Task Settings (40%), about 28% is received and processed by the Architects (11%); effectiveness-factor: 0,28. In Design Task Setting X1 and Y1 the effectiveness-factor of the sent items is received and processed by the Architects is between 0,68 and 0,74 compared to about 0,50 in Design Task Setting Y2.

Overall the effectiveness of the sent function-types and sub-solutions by the Contractor is higher compared to the Architect. This gives an indication that the role of the Contractor is positive related to interaction of object- and realization-knowledge.

This analysis demonstrates that the the face-to-face setting provided by the workshops did allow the Contractors to collaborate substantially with the Architects through a variety of mediums. This finding is particulalry encouraging since working collaboratively on a design task with a specific Morphological Overview in such an environment was a new experience for most if not all the Contractors. However, one particular result requires further consideration. When the Morphological Overview was used, the contributed function-types of Contractors were at their lowest level. One plausable explanation for this finding is that when the Morphological Overview is used, the Architect is more likely to take responsibility for what is and is not notated in the tool. In this sense, the Architect seems to be adopting the pivotal position in the process as in the status quo in practice. Accordingly, the Contractor's role is likely to be more reactive, as in the status quo, rather than proactive and with less design experience compared to the Architect, as is desired in a collaborative team approach to design. However, it must also be pointed out that the order in which the Morphological Overview was introduced did have an effect on the level of contributions of Contractors.

These results give an indication that a step by step approach in which the practitioners are first required to focus solely on working on the design task before being introduced to the Morphological Overview is more effective than simultaneously imposing working on the design task and the Morphological Overview. Perhaps unsurprisingly, this result is particularly true for the Contractors. The clearest evidence of this result is that in group X, in which the first task presented an opportunity to practice design without the Morphological Overview. In the second task in this setting, a greater number of communicative exchanges involving Contractors was identified; 3% more related to function-types and 17% more related to sub-solutions. This indicates that the setting of group X in the DWS is a suitable basis to train CD-teams.

3. MAF 3 Analysis

While the previous view set out to identify communicative exchanges relating to function-types, the current view goes further by determining how many and what kind of function-types were notated in the different settings. The notated object-related and realization-related function-types and sub-solutions will provide an indication of the level of collaboration between the Contractors and Architects since Architects are expected to contribute the majority of object-knowledge while the majority of realization-knowledge is expected to be contributed by the Contractors. The extent to which the notated function-types are representative of the reference-list (Figure 15, page 71; 25 function-types) will provide an indication of the extent to which the teams contributed the necessary items for an Integral Design.

The Morphological Analysis Format 3 (MAF 3) was used to determine the different function-types notated during the design-process for the different Design Task Settings. The MAF 3 format uses a coding to represent different types of function-types and different means of communication. The results from all of presented of the MAF 3 were combined into one comprehensive table, presented in

Figure 64 on page 142. In Appendix 10 (page 111 – 119) the MAF 3 analysis of each Design Task Setting of DWS01 and DWS02 are presented, with the different steps to generate the total overview as presented in this Chapter.

Figure 67 on page 146 shows the contributions of the teams related to the reference-list of function-types (25 function-types); of these function-types 11 are realization-related and 14 object-related). In the overview the average notated function-types are related to these knowledge-types. Thus, if any of the function-types from the reference list are not notated, then the total percentage of object- and realization-knowledge will be less than 100%. For example for Task 2 (X1); 9,5 + 6,5 = 16,0 function-types are notated out of 25 reference-list, which is 64%. Realization-related notated function-types for Task 2 (X1) though are 6,5 out of 11 = 59%, notated between brackets. Next to the function-types, the table presents the percentage of notated sub-solutions in the teams. For the sub-solutions there is no strict reference. Here, the total of the notated sub-solutions of all teams within a design task is 100%. In Figure 67 between brackets per Design Task the number of monitored teams.

KNOWLEDGE-TYPE	SOLUTION-TYPE	TASK 2 NMO / X1 B1, B2, B3 (6)	TASK 2 MO1 / Y1 B5, B6, B7, B9, B10 (6)	TASK 3 MO1 / X2 C1, C2, C3 (6)	TASK 3 MO2 / Y2 C5, C6, C7, C8 (5)
REALIZATION	FUNCTION-TYPES	6,5 out of 11 (59%)	6,5 out of 11 59%)	9,5 out of 11 (86%)	7,8 out of 11 (71%)
	SUB-SOLUTIONS	44 out of 129 (34%)	54 out of 174 (31%)	78 out of 156 (49%)	71 out of 156 (34%)
OBJECT	FUNCTION-TYPES	9,5 out of 14 (68%)	11,5 out of 14 (82%)	9 out of 14 (64%)	11,4 out of 14 (81%)
	SUB-SOLUTIONS	85 out of 129 (66%)	120 out of 174 (69%)	81 out of 156 (51%)	85 out of 156 (66%)
TOTAL	**FUNCTION-TYPES**	**16 out of 25 (64%)**	**18 out of 25 (72%)**	**18,5 out of 25 (74%)**	**19,2 out of 25 (77%)**

Figure 67 Overview for DWS Total: notated object- and realization-related function-types and sub-solutions.

Figure 67 shows the extent to which the reference list has been covered by the object-related and realization-related function-types and sub-solutions notated by the groups X and Y. What can be determined is that in all Design Task Settings the average total percentages of the reference-list notated are high; 59% or more.

With an overall view related to function-types, we can compare the different Design Task Settings of group X and Y. It is worth pointing out that the total percentages can only be high if the majority of object and realization-related function-types have been notated. Figure 67 shows, the highest total percentage coverage of the reference list, 77%, was found in group Y2 (average 81% object-related and 71% realization-related notated function-types). This figure was closely followed by the coverage of Task 3 MO1 group X2: 74% (64% object-related and 86% realization-related function-types). Consideration of the other conditions seems to add some weight to the above point. The lowest percentage coverage of the reference list was found in the Design Task Setting in which the Morphological Overview had not been introduced and therefore could not be used by the teams (group X1). Here, the total percentage was 64% (68% object related and 59% realization related function-types).

In all conditions, except for the situation in group X and Y for object-related sub-solutions which is more or less equal in percentages, there is an increase of notated realization-related function-types and sub-solutions when the Workshop progresses and the Morphological Overview (MO) is loosely introduced to the CD Team. This is an early indication, which will be investigated further in the analysis of RQ8 and RQ9, that the MO may indeed improve the chances of a Collaborative Design Team producing an Integral Design for roofs.

4. Answer to RQ7

Whith the analysis of Photographs, Video Recordings and the MAF 3 the following can be concluded. The analysis of photographs and the associated discussion with the trained assistants revelaed a clear pattern of interaction between the Architects and the Contractors. The susbequent analysis of the video recordings using the Video Observation- and Video Interaction Formats identified interaction

in the various mediums used by the teams, including speech, sketches, written notes and notations in the Morphological Overview. The final step in the analysis used the MAF 3 format to provide a more in depth understanding of the notated function-types and sub-solutions. In particular, it was shown that while the Architect may take a more dominant role in some of the settings, the Contractors did succeed in communicating a significant ammount of function-types and sub-solutions in all settings. This success is a likely explanation for the good balance between the object-related and realization-related function-types and sub-solutions that were notated. Now the RQ7 can be answered.

RQ7 *Did the face-to-face setting provided by the workshop allows collaboration between the practitioners working on the design task?*

ARQ7 Practitoners working on complex design tasks within CD teams in the Collaborative Design Workshop are challanged to use different types of communication and represenation to put forward, discuss and develop specific object- and realization-knowledge. Communication and representation are effective when the sender and receiver are in interaction with each other about the design task.

With the Video Interaction Format that was used and tested in the research project the differerent types of communication could be determined in the face-to-face setting between the different practitioners within the design-teams. The results show that all over a variety of communication types (speech, sketch, MO) were used by and between the different designers and Contractors. Although the Architects are the most active practitioners in notations, the step-by-step introduction of the Design Task, CD Team and Morphological Overview gives the Contractors an improved Practice Setting to collaborate.

3.4.2.1 C3 Collaborative Design Team

While the answer to RQ7 above showed that the Collaborative Design Workshop did allow for interaction between the practitioners, it is now necessary to determine whether this interaction represented the desired collaboration required to complete the Design Task sufficiently. Essentially, if all of the items from the list have been notated, then the contributions of the team can be described as sufficient. A design must be sufficient to be classified as an Integral Design for roofs. More specifically, it is important to determine whether or not both the Architects and the Contractors managed to make especially realization-related contributions for the design tasks at hand. Related to the role of the practitioners, the contributions of the Contractor compared to the Architect are the focus.

To determine whether the contributions of Architects and Contractors are as expected, the Improved Research Analyses Protocol, which was developed in the Prescriptive Study, is used. During this analysis, the reference list of function-types and related sub-solutions derived from the competence profiles (see also Figure 15. Page 71) is used to represent the necessary key-components of an Integral Design. Essentially, if all of the items from the list have been notated, then the contributions of the team can be described as sufficient. A design must be sufficient to be classified as an Integral Design for roofs.

In line with the Improved Research Analyses Protocol, the data gathered from three main formats are used. These formats are the Video Observation- and Video Interaction Format in reference with the Morphological Analysis Format.

A full demonstration of this how this Improved Research Analyses Protocol is applied is shown in Appendix 12.4 (Example 5, page 167 – 176). In what follows, the results of team contributions are presented first before moving on to the individual contributions.

1. Results of team contributions related to RQ6

The average contributions per CD Team for the contributed object- and realization-knowledge are presented in an overview for all different Design Task Settings as average of the two Definitive Collaborative Design Workshops (DWS) (Figure 67, page 146). This overview is derived from the analysis from the Video Observation Formats (VOF) in the Morphological Analysis Format 3 (MAF 3) and an additional use of both formats. So the use of the MAF 3 is twofold: first it is used to view the variety of function-types as one of the parameters for collaboration (RQ7) and second it is used to determine the team contributions within a specific Design Task Setting (RQ6).

The used reference-list of the function-types has 25 function-types in total of which 14 are object-related function-types and 11 are realization-related function-types. The same way of calculation is executed as with the table in Figure 67 on page 146. The percentages for the object- (14) and realization-knowledge (11) refer to the total amount of the function-types per knowledge-type. The percentage Total refers to the total amount of all average notated function-types related to the 25 function-types of the reference-list (100%).

Before looking further into the contributed function-types and related sub-solutions, it is worth recalling an earlier observation. Many of the problems with designs in practice, like those of the Case-Studies (3.2.1), are associated with a lack of introduction of realization knowledge. Thus, the focus here is on the realization-related contributions in the different Design Task Settings.

The first result to mention is that when the MO is not introduced (X1) the percentage of notated realization-related function-types (59%) is the lowest compared to all other design tasks (X2, Y2), but equal with design tasks group Y1. All other Design Task Settings have a higher percentage of average notated realization-related function-types: Y2; 71% and X2; 86%. This means that without the MO in average, 6,5 out of 11 realization related function-types from the reference list are notated and with the use of the MO this average rises to 8 out of 11. What can also been observed is that in group X the percentage of notated realization-knowledge increases as the settings progress as well for the notated function-types (X1: 59% to X2: 86%) as sub-solutions (X1: 34%, X2: 49%). In group Y there is a more or less the same tendency for function-types (Y1: 59%, Y2: 71%) as well as realization-related sub-solutions (Y1: 31%, Y2: 34%). There is a larger increase for average notated items in group X compared with group Y.

These results are related to the teams. As noted in WS04, the next step is executed to determine whether the individual practitioners within these teams contribute realization-related knowledge. The same Formats that were used to analyze the teams were used for the analysis of individual contributions

2. Results individual contributions related to RQ6

For the individual contributions the following two overviews presented; one as a table and the second in a graphical format (Figure 68 and Figure 69). This is a summary of the results extracted from the different Video Observation Formats (VOF) and Video Interaction Formats (VIF) for each team in a specific Design Task Setting. With the VOF the contributions by the participants of amount of object- and realization-related function-types and sub-solutions was determined and in steps combined from individual Design Teams to overviews of all teams within one Design Task Setting per DWS and finally in average notated for all monitored teams: DWS Total. This step by step analysis for all Design Teams, as derived from the use of the VOF and VIF, is presented in tables and graphs in Appendix 9. An example of this analysis is presented in Appendix 12.4. (Example 5, page 167 – 176).

Thus, the first step was to identify and record all of the notated function-types types and sub-solutions in sketches and MO from each team. The next step was to determine who had contributed what. The overview of the contributions in average notated items is presented in Figure 65. In this overview the

group X1 is the only group where no MO is introduced; in all other groups the MO was introduced. In Figure 65, in the DWS Total for each Design Task: an overview with the average of the notated object- and realization related function-types and sub-solutions by Architects and Contractors per Design Task Setting. Notated between brackets in Figure 68: the number of Design Teams which were monitored and analyzed.

PARTICPANT TYPE	KNOWLEDGE-TYPE	TASK 2 NMO / X1 B1, B2, B3 (6)	TASK 2 MO1 / Y1 B5, B6, B7, B9, B10 (6)	TASK 3 MO1 / X2 C1, C2, C3 (6)	TASK 3 MO2 / Y2 C5, C6, C7, C8 (5)
ARCHITECT	REALIZATION	11,3 (75%)	13,8 (82%)	15,7 (56%)	26,3 (85%)
	OBJECT	30,2 (86%)	36,5 (82%)	17,2 (63%)	26,2 (81%)
TOTAL ARCHITECT		**41.5 (91%)**	**50,3 (82%)**	**32,9 (59%)**	**52,5 (83%)**
CONTRACTOR	REALIZATION	3,7 (25%)	3,0 (18%)	12,5 (44%)	4,5 (15%)
	OBJECT	4.8 (14%)	7,8 (18%)	10,3 (37%)	6,0 (19%)
TOTAL CONTRACTOR		**8,5 (9%)**	**10,8 (18%)**	**22,8 (41%)**	**10,5 (17%)**

Figure 68 DWS Total Contributions Practitioner-type: percentage of average of the notated object- and realization related function-types and sub-solutions per Design Task Setting.

In order to provide a clearer picture of the results, it is useful to consider how the contributions differed throughout the various settings. A quick yet global picture can be seen in a comparison of group X (Task 2 NMO – Task 3 MO1) and group Y (Task 2 MO1 – Task 3 MO2). When viewing these results the following aspects are important and can be viewed as positive. First: if there is a balance in contributions from Architects and Contractors. Second: if there is contributed realization knowledge by Architects and especially Contractors. Third: if there is an increase in contributed amount of realization knowledge in the successive Design Tasks. Most optimal is the situation where all realization related function-types from the reference list were contributed by Architect and Contractor.

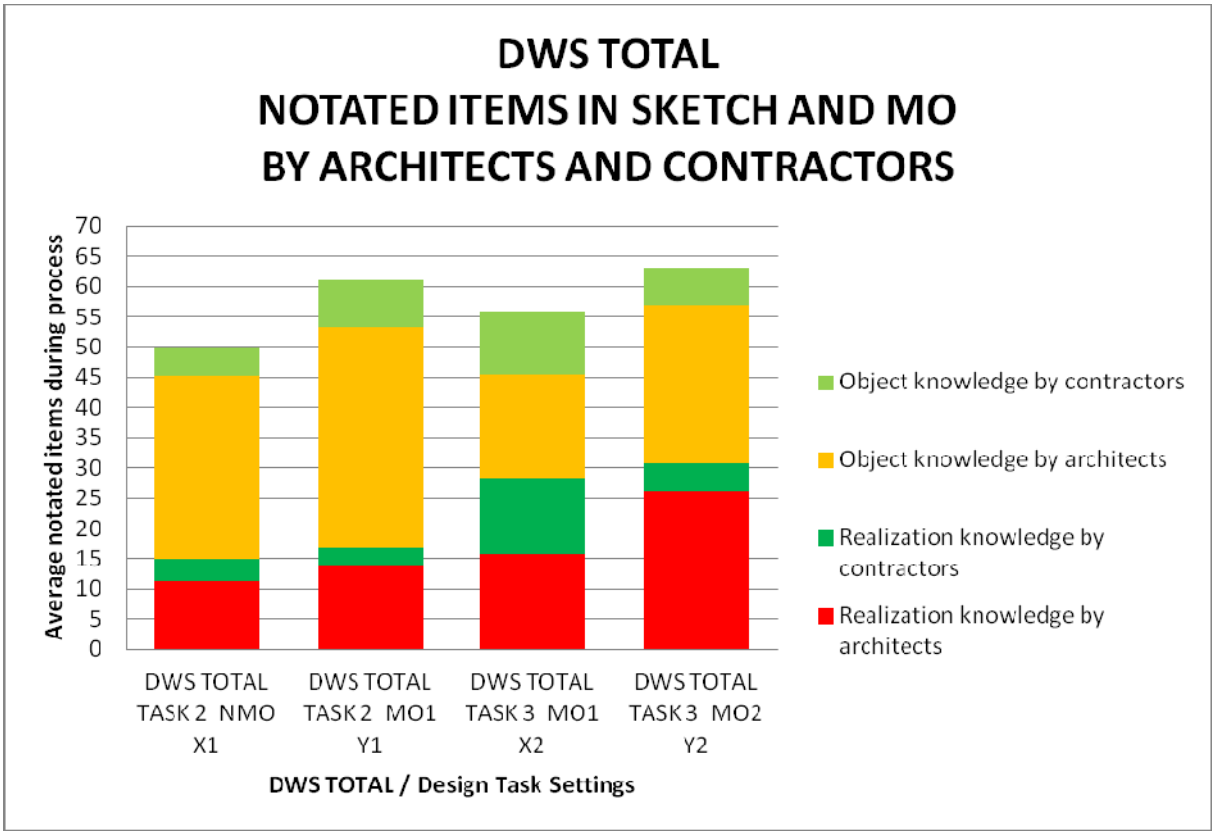


Figure 69 DWS Total Contributions per Practitioner-type: average of the notated object- and realization related function-types and sub-solutions per Design Task Setting, graphical representation.

When comparing teams from group Y and X the following results can be viewed. Overall the Architects make the most contributions in all Design Task Settings. For group X1 task 2 NMO (91%) and Y2 task 3 MO2 (83%) the Architects have the highest score. Group Y1 task 2 MO1 has more or less the same score for the contributions of the Architects as Y2: 82%. Only group X2 task 2 MO1 is an exception, in this Design Task Setting the Contractors make 41% of the contributions and Architects 59%. This Design Task Setting X2 is the setting where there is the most optimum balance between contributions of Contractors and Architects compared to the other Design Task Settings. The explanation of this result is the same as the explanation for this finding on the level of the teams. It appears that an incremental introduction to the Collaborative Design Workshop is more suitable for the Contractors. When the Contractors are first allowed to practice design while working on a task in a team setting, they perform better than when the MO is subsequently introduced than they do when it is introduced simultaneously with working on a design task. In brief, this simultaneous introduction of working collaboratively on a design task and using the MO seems overly complicated for the Contractors. However, in group Y there is a contrary tendency; in Task 2 MO1 (Y1) the Architects contribute an average 82% and in Task 3 MO2 (Y2) the average contribution of the Architects slightly increases to 83%. This gives an indication that the Architects seem to be comfortable with the use of the MO.

The more refined picture compares only the realization related knowledge contributed by Architects and Contractors in the different Design Task Settings. In the comparison the focus is on the contribution of the realization-related function-types and related sub-solutions to verify if the collaboration of Architects and Contractors in the different Design Task Settings is indeed effective.

First analysis of realization-related results is on team-level. Before turning to the most productive settings, it is worth considering which setting proved least productive in terms of average realization-related notations. The Design Task Setting without the loose introduction of the MO, X1, has the lowest level of coverage of realization-related notations (X1 realization: 11,3 + 3,7 = 15). When compared to other Design Task Settings this score is followed by group Y1 task 2 MO1 (Y1 realization: 13,8 + 3,0 = 16,8). In the subsequent Design Task Settings the score related to notated realization-related notations is always higher (X2: 28,2, Y2: 30,8), which is a positive tendency on team-level.

The individual notation of realization-related function-types and sub-solutions is the second analysis from these results in Figure 68, page 149. Overall, the most realization-related notations are by the Architects, with the highest score in group Y2 task 3 MO2: 26,3. The highest score for the Contractors is in group X2 task 3 MO1 with in average 12,5 realization-related notations. Related to the Design Task Settings and the loose introduction of the MO the following results can be viewed on practitioner-level. For Architects in group X there is a slight increase of notated realization-related items (Architect Realization, X1: 11,3, X2: 15,7), whereas in group Y there is almost a doubling (Architect Realization, Y1: 13,8, Y2: 26,3). For Contractors a contrary tendency can be viewed with a better score in group X compared to group Y. In group Y there is a slight increase (Contractor Realization, Y1: 3,0, Y2: 4,5). In group X there is a significant increase (Contractor Realization, X1: 3,7, X2: 12,5).

This increase of notated realization-knowledge is another criterion to analyze the results. When comparing group X and Y, in both groups there is an increase of notated realization-knowledge in the successive Design Tasks. For Architects group Y is most positive but for the Contractors group X, which is also more positive in the balance in contributions between the different practitioners. In group Y there is a tendency that the Architect is more dominant in contributions in the successive Design Task, with a decrease of the contributions of the Contractors. In group X the tendency is more positive for the role of the Contractor with an increase of contributed items and especially realization-knowledge and a balanced situation within the Design Teams.

On reflection of the above results, an important observation needs to be made about one setting in particular. In setting X2, the highest level of overall coverage and the highest level of coverage of the

Contractors were identified. In setting X1 the teams had not been loosely introduced to the Morphological Overview. However, the subsequent X2 setting began by introducing the teams to the Morphological Overview before the design task began. Thus, X2 could be described as the conclusion of a step by step learning process in which the teams are first required to adopt designing while working collaboratively on a design task before being asked to repeat the process with the use of the Morphological Overview.

3. Answer for RQ6

The aim of the above analysis was to determine to what extent the reference-list of function-types had been covered by the teams, and to discover which Design Task Setting represented the most productive for contributions from the individual practitioners, with the focus on realization-knowledge.

In general, it was evident that in all of the settings the use of the Collaborative Design Workshop did allow both types of practitioners to contribute realization-knowledge. Furthermore, it became clear that both type of practitioners contributed a greater amount of realization-knowledge when the MO was used compared with the Design Task Setting where it was not used. One particular setting turned out to be significantly more productive than the others. In setting X2, the contributions of realization-knowledge by Contractors were four times that of group Y1 and treble for Y2 of those notated in other Design Task Settings. The likely explanation for this finding is that Design Task Setting X2 represents the most incremental yet systematic introduction of the key elements of the Collaborative Design Workshop: designing, task driven collaboration; and the use of a MO to structure and organize contributions from the different practitioners in the CD Team.

With these results we now can answer the related Research Question RQ6

RQ6 *Did both types of practitioners succeed in contributing realization knowledge?*

ARQ6 To fulfill the complex Design Tasks specific object- and realization-knowledge needs to be contributed and developed by the different practitioners within the Practice Setting as the basis of Integral Roof Designs. These specific contributed function-types of knowledge, as represented by the reference-list, have to be applicable to the Design Task. They are sufficient when no realization-knowledge is missing which is needed to design and realize an Integral Roof Design.

The Video Observation Format, developed in WS04 and WS05, and Video Interaction Format, developed in WS05, were used to determine the different types of contributed object- and realization knowledge of Architects and Contractors in the CD teams. By using the Collaborative Design Workshop overall the individual practitioners made design-task contributions, although in such teams it is difficult to generate sufficient realization-knowledge, contributions for an Integral Design for roofs as a solution to a complex task in the given time-frame.

3.4.2.1 C4 Morphological Overview

The reason that the Morphological Overview (MO) was included as a core key-component of the Collaborative Design Workshop (DWS) is that it is expected that the tool would provide the CD teams with a cleaerer focus for the design task and a user friendly means to sytematically structure and organise relevant task related knowledge. The clearer focus offered by the tool arises because it forces the practitioners to contribute, discuss and notate relevant knowledge in the form of function-types and related sub-solutions. The simple matrix structure of the tool allows for quick and easy recording of contributed function-types.

While it was expected that the MO would have a positive effect on the output of the design teams, due to practice-experience and literature-references (page 64 – 71) a starting point was that firm prescription of the tool may lead to its rejection by competent practitioners. In order to increase the reliability of fthe results, it was considered important to give the teams the freedom to adopt the MO or not in the settings in which it was introduced. In these Design Task Settings, the MO can be described as loose introduced. Therefore, for the effect of the MO, first step was to determine the extent to which the teams accepted the use of the tool.

The previously described Improved Research Analyses Protocol was applied here to investigate the two Research Questions relating to the MO. First, the acceptance of the MO (RQ8) and second the effect of the MO on the contributions of the teams and o the different types of practitioners (RQ9). The results are presented in order of the Research Question numbers.

Results for the acceptance of the Morphological Overview (RQ8)

To answer this Research Question, the influence of the use of the MO in the different design-tasks settings has to be determined. There are three data-sources used. The first data-source which is used are the produced documents by the teams and the photographs of these documents. The second data-source which is used are the video-recordings of 3 teams per Design Task. The results are the analysis of video-recording of each team by the Video Observation Format (VOF) and organized in the Morphological Analysis Format (MAF 3). An example of the analysis for RQ8 is presented in Appendix 12.5 (Example 6, page 177 – 179). The third data-source is the format of the pre-defined questionnaire and in the interviews after 6 months, this to done to gain insight in the personal evalutations of the practitioners.

1. Results quick-scan; using produced documents and photographts as data-source

To get a first impression of the use of the MO a quick-scan was used with the use of the produced documents and photographs. During the different DWS it could already be observed that a majority of the design-teams where using the MO. The photographs in Figure 70 show some representative examples. These pictures show also that both Architects and Contractors where using the MO, on their own or working together using the MO in a shared format. The MO was, as the pictures show, in various ways convenient to the way of working of the competent professionals and the way they worked together in teams.

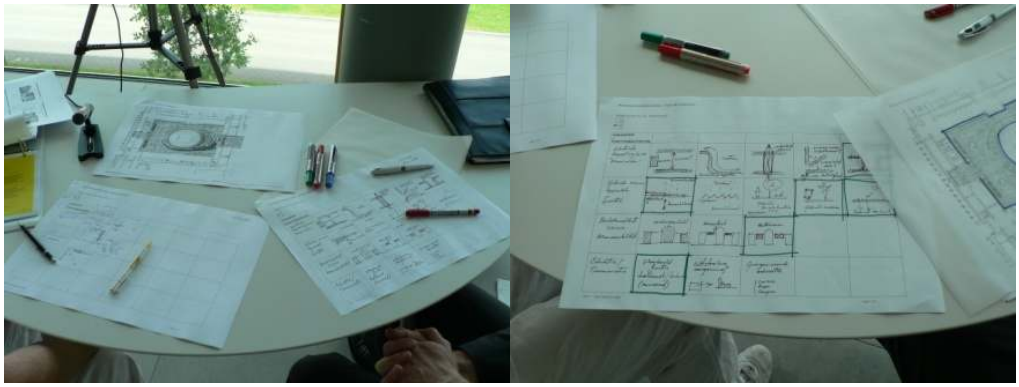


Figure 70 Some examples of the different situations during the different design-task sessions for DWS for the use of the Morphological Overview.

The result for the use of the MO by the teams in the different Design Task Settings are presented in Figure 71.1 with a comparison of the different Design Task Settings: Task 2 MO1 (X2), Task 3 MO1 (Y1), Task 3 MO2 (Y2) and the average for each setting and for all DWS. In Figure 71.1 and 71.2 the *

refers to the situation that one Design Team was not monitored because of damaged video; average of 2 teams. Between brackets the number of Design Teams monitored.

DWS	TASK 2 MO1 / Y1 B5, B6, B7, B9, B10 (6)	TASK 3 MO1 / X2 C1, C2, C3 (6)	TASK 3 MO2 / Y2 C5, C6, C7, C8 (5)	TOTAL DWS
DWS 01	3 (3)	2 (3)	2 (3)	7 (9)
DWS 02	3 (3)	3 (3)	2 (2) *	8 (8)
TOTAL / TASK	**6 (6)**	**5 (6)**	**4 (5)**	**15 (17 = 88%)**

Figure 71.1 DWS Total: overview of the amount of teams which used the Morphological Overview (MO) per Design Task per DWS.

All over there is a positive use of the Morphological Overview when loose introduced to the practitioners / teams. When loose introduced the average use of the Morphological Overview is about 88% of all teams. In DWS01, 7 out of 9 teams used the MO in DWS02 all teams used the MO. There is one remark to be made related to these table; in DWS 02 one team in group Y2 (marked result *) was not viewed with video because of a damaged tape. This design team though was not taken into account for the result. In total a majority of the design teams used the MO when it was loose introduced in the different Design Task Settings.

DWS	PRACTITIONER	TASK 2 MO1 / Y1 B5, B6, B7, B9, B10 (6)	TASK 3 MO1 / X2 C1, C2, C3 (6)	TASK 3 MO2 / Y2 C5, C6, C7, C8 (5)	TOTAL / PRACTITIONER
DWS 01	ARCHITECT	3 (3)	2 (3)	2 (3)	7 (9 = 78%)
	CONTRACTOR	0 (3)	1 (3)	0 (3)	1 (9 = 11%)
DWS 01 TOTAL		3 (6)	3 (6)	2 (6)	8 (18 = 44%)
DWS 02	ARCHITECT	3 (3)	2 (3)	1 (2)*	6 (8 = 75%)
	CONTRACTOR	2 (3)	2 (3)	1 (2)*	5 (8 = 63%)
DWS 02 TOTAL		5 (6)	4 (6)	2 (4)*	11 (16 = 69%)
ARCHITECTS TOTAL		6 (6) = 100%	4 (6) = 66%	3 (5) = 60%	13 (17) = 76%
CONTRACTORS TOTAL		2 (6) = 33%	3 (6) = 50%	1 (5) = 20%	6 (17) = 35%
DWS TOTAL / TASK		**8 (12)**	**7 (12)**	**4 (10)**	**19 (34 = 56%)**

Figure 71.2 DWS Total: overview of the amount and percentage of practitioners which used the Morphological Overview (MO), per Design Task, per DWS.

On practitioner level Figure 71.2 gives an overview of the use of the MO, between brackets the number of practitoners which were monitored are presented. Over all for both DWS 19 out of 34 practitioners used the MO, which is 56%. In total 13 out of 17 Architects (76%) used the MO and for the Contractors, 6 out of 17 (35%) practitioners used the MO. In DWS01, 8 out of 18 practitioners (44%) used the MO and in DWS02, the MO was used by 11 out of 16 practioners (69%) of the practitioners. What also can be viewed is that there is a significant difference in use of the MO by the Contractors in DWS01 (11%) compared to DWS02 (63%), whereas for Architects the results for the use of the MO are more comparable (DWS01: 78%, DWS02: 63%).

When comparing the use of the MO on design task-level the results are as follows. In all Design Task Settings the Architects used the MO more or equal compared to the Contractors. When the MO was used the first time in the setting Y1, all Architects in both DWS 01 and DWS 02 used the MO compared to two third of the Architects use the MO in group X2. For Contractors a contrary comparison can be made; in group Y1 one third of the Contractors used the MO compared to group X2 where half of Contractors used the MO. In group Y2 the lowest results can be viewed for both Architects and Contractors.

For the Architects it can be observed that when introduced the second time, the use of the MO decreases to 50%, where in the step by step setting the use is more in balance although lower compared when immidiatley introduced. What can be determined from this comparisons is that for the Contractors a step by step introduction of the MO is more effective compared to the immidiate introduction of the MO.

2. Results notated function-types and sub-solutions in the Morphological Overview: using video-recordings as data-source

The second step in answering the use of the MO is to determine the notations in MO as part of the total notated function-types (all notated function-types in sketches and MO: 100%) and related sub-solutions are also notated in the MO (all notated in sketches and MO: 100%). The results are derived from the analysis through the Video Observation Format (VOF) and notated in the Morphological Analysis Formats (MAF 3) per Design Task. In Appendix 10 the used MAF 3 derived from the analyses of DWS01 and DWS02 (Appendix 10, Figure 10.13 and Figure 10.14, page 122) and organized in an overview to compare the Design Task Settings (Figure 10.15, page 123) are presented. Presented in Figure 72 are the amount of function-types and sub-solutions notated in the MO out of the total amount of function-types and the corresponding percentage in brackets.

DWS	SOLUTION-TYPE	TASK 2 MO1 / Y1 B5, B6, B7, B9, B10 (6)	TASK 3 MO1 / X2 C1, C2, C3 (6)	TASK 3 MO2 / Y2 C5, C6, C7, C8 (5)
DWS 01	FUNCTION-TYPES	20 out of 23 (87%)	9 out of 16 (56%)	14 out of 21 (67%)
	SUB-SOLUTIONS	76 out of 96 (79%)	38 out of 80 (47%)	43 out of 85 (50%)
DWS 02	FUNCTION-TYPES	9 out of 13 (69%)	15 out of 21 (71%)	10 out of 18 (55%)
	SUB-SOLUTIONS	46 out of 78 (59%)	39 out of 79 (79%)	33 out of 71 (46%)
DWS TOTAL	FUNCTION-TYPES	14,5 out of 18 (81%)	12 out of 18,5 (65%)	12,4 out of 19,8 (63%)
	SUB-SOLUTIONS	127 out of 174 (73%)	77 out of 159 (48%)	76 out of 156 (49%)

Figure 72 Table with overview of the percentage of notated function-types and sub-solutions in the Morphological Overview (MO).

Related to the influence of the MO related to the notated function-types and sub-solutions the focus is on the Design Task Settings.

The first analysis of Figure 72 is on the notated function-types and sub-solutions in the MO per DWS. The percentages in Figure 72 give a mixed picture for DWS 01 and DWS 02. In both DWS there is a decrease in notated function-types. For group Y, where the MO is introduced in both Design Task Settings (DWS 01; Y1: 87%, Y2: 67%, DWS 02: Y1: 69%, Y2: 55%) compared to group X (DWS 01; X2: 56%, DWS 02: X2: 71%). For sub-solutions notated in the MO the percentage is most positive in the settings when MO is first time introduced (Task 2 MO1; X2 and Task 3 MO1; Y1); the percentage decreases when second time introduced (Task 3 MO2; Y2) in both DWS, although in DWS01 in Y2 there is a slightly higher percentage in Y2 (50%) compared to X2 (47%).

The second analysis is the overall comparison on notated function-types and sub-solutions, as presented as DWS Total in Figure 72. The results for DWS Total show the following results. For notations of function-types group Y1 task 2 MO1 (81%) has the highest amount of notated items compared to group X2 task 3 MO1 (65%) and Y2 task 3 MO2 (63%). For function-types in group Y there is a decrease of notated function-types, so less notated function-types when the MO is loose introduced the second time (Y1: 81%, Y2: 63%). When introduced the first time the notations of function-types in Y1 task 2 MO1 (63%) and X2 task 3 MO1 (65%) are comparable.

For the notation of sub-solutions in the MO less sub-solutions are notated in the MO compared to the same situation where the MO is first loose introduced; 48% in task 3 MO1 (X2) compared to 73% in

task 2 MO1 (Y1). Compared with group Y2, there is more or less the same situation as in group X2. When immidiately loose introduced in a Team (Y1) the notations in the MO for both function-types and sub-solutions are highest compared to both other Design Task Settings for group X2 and Y2. When loose introduced the second time (Y2), notations in the MO in average decrease and are more or less the same as in group X2 with the step by step situation.

What these analyses show is that in almost all Design Task Settings more than 50% of the notated function-types and sub-solutions is also notated in the MO, which is a positive tendency. Additionally two important aspects have to be considered. First, the MO is introduced as a support tool and not as a tool to design, so it can be expected that more items are discussed and notated in the MO but not used in the development of the design. The second consideration is that in this setting with the 'pressure cooking' time-frame and the first time teams working together and using a new MO it is positive that the MO is used in the way it is convenient to the practitioners in the teams.

3. Results of the pre-defined questionnaire as data-source

The third step in analysing the acceptance of the MO used the data-sources of pre-defined questionnaires and pre-defined interviews after 6 months. First the results of the pre-defined questionnaires are presented which where used directly after the workhops. For all DWS all practitioners returned the pre-defined questionnaires, except for 50% of the Contractors in DWS 02. , with 100% returned questionaires (Figure 73). In this Figure 73 the coding for Architects is A and C for Contractors. The following rating where introduced to the practitioners and the score used for the researcher between brackets, 1: poor (2), 2: insufficient (4), 3: sufficient (6), 4: good (8) and 5: very good (10).

DWST TOTAL Rating 1-5 Likert-scale	Q1 How important use MO to your practice	Q4 Use of MO - general	Q5 Useful to stimulate use MO within practice	Q6 Expectation future use of MO
DWS 01 A average	3,1	3,3	3,4	2,9
DWS 02 A average	3,4	3,5	3,2	2,8
DWS T A average	3,2	3,4	3,3	2,8
DWS 01 C average	2,8	3,2	3,6	3,3
DWS 02 C average	3,7	3,3	4,0	3,7
DWS T C average	3,2	3,2	3,8	3,5
AVERAGE TOTAL	3,3	3,3	3,5	3,2

Figure 73 Average outcomes Pre-defined quesionnaire (fragment) directly after the workshops: related to the adoptation and use of the Morphological Overviews as Morphological Overview.

The overview of Figure 73 shows that the average overall rating by the practitioners for the MO is positive in general as well as related to their own and future practice. Significant is that all practitioners indicate that that it is important to stimulate the use of the MO in practice. More specific related to the practitioner-types the following tendencis can be observed. Architects and Contractors rate equally on the importance of the MO for their own practice (average 3,2). The use of the MO in general was rated more positive by the Architects (average 3,4) compared to Contractors (average 3.2). Stimulation of the MO for practice is rated more positive by Contractors (average 3,8) compared to Architects (average 3,3). An indication on the future use of the MO gives the last question. This gives an indictition that Contractors experienced the MO important to have as part of their competence. This

is confirmed by the last question for expected future use. The Contractors are more positive about the future use (average 3,5) compared to the Architects (average 2,8).

More interesting are, however, the evaluations after 6 months through the pre-defined interviews by the trained assitants. The pre-defined interview questions are given in Figure 74 full overview of the results of the pre-defined questionnaires and interviews is presented in Appendix 14 (page 191 – 195).

INTERVIEW FORMAT DWS	OPEN QUESTIONS
Q1. Can you remember the Collaborative Design and the use of MO? How did you experience both?	
Q2. Did you use the MO in the meantime? - Yes, for which purpose, in which situations? - No, because....	
Q 3. If you used the MO, how where your experiences for yourself and for the other team- members?	
Q 4. Should this approach of Collaborative Design and MO be stimulated in education for professionals and students?	

Figure 74 Interview Format DWS; after 6 months.

Average response on all practitioners for the two DWS was 55%. Average response of the Architects was 63%, for the Contractors 47%. Almost all interviewed practitioners (Q1: 89%) could remember the DWS and the use of the MO after 6 months and had a very positive response on the experience. When related to the real use of the MO in practice the result is rather poor; only 3 out of the 20 practitioners interviewed (Q2: 15%) – only Architects – used the MO in practice. They experience the way of working as structuring problems on different abstraction levels and related to practice. The response of all other interviewed practitioners was related to Architects and the majority installers that they have their own methods in practice. All interviewed roofers point out that in their practice normally thy don't have the opportunity to work with designers and in other practice-situations they don't use this type of support tools. Of the interviewed practitioners 79% (Q4) underpin that the Collaborative Design Workshop and the introduction and use of the MO should be stimulated in education for professionals and students, 11% is ambivalent about this and 10% negative. The negative response was of Architects which experienced the use of the MO not positive for themselves and found it more related to the other practitioner-types, the Contractors. Conclusion for the evaluation with the practitioners is that a majority of the interviewed practitioners is positive about the MO for use in practice and education, although until now the majority of the interviewed practitioners did not use the MO.

4. Answer for RQ8

In conclusion, to answer RQ8, three data-sources were exploited in order to determine the acceptance of the Morphological Overview (MO) in the Definitive Collaborative Design Workshops (DWS).

The results for the use of produced document and photographs as data-source show that in a majority of Collaborative Design teams used the MO in the different Design Task Settings. Thus, loose prescription of the MO did not lead to its rejection by the teams.

With the use of the video-recordings as second data-source more detailed results were presented. In general about 88% of all teams used the MO in their design process and 19 out of 34 participants (56%) used the MO for the Design Task. Related to the type of practitioner the Architects (76%) used the MO about twice as much as the Contractors (35%). Overall observation is that more than 50% of all notated function-types and related sub-solutions which are generated by the teams in the design process are also notated in the MO. The most productive settings in terms of the amount of notated function-types types and sub-solutions from the teams was the Design Task Setting where the MO was loose introduced for the first time: group Y1 task 2 MO1 and group X2 task 3 MO1. Because there

is a negative tendency when the MO is loose introduced the second time (group Y2 task 3, MO2) a step by step introduction of the approach and the MO is viewed as most positive.

The results of the questionnaires administered directly after the workshops were positive in general for all practitioners. There was overall agreement that the Collaborative Design Workshop with the use of the MO was a productive way to stimulate collaboration and knowledge exchange (Q2, Appendix 14). Similarly, all practitioners agreed that the Collaborative Design Workshop should be included in the educational programs of both students and professionals. In addition, they all thought that it was important to stimulate the use of the approach in practice.

The results of the interviews that were conducted 6 months after the workshops had been completed gave a more mixed picture. All of the different practitioner-types remained positive about their experiences during the Collaborative Design Workshops and their belief in the importance of promoting the future use of the approach in education and practice. However, only a small minority of the practitioners, all Architects as it happens, had actually applied the MO in practice since attending the workshop.

With these analysis we can now answer the following Research Question.

RQ8 *Did loose introduction of the Morphological Overview lead to acceptance of the tool?*

ARQ8 In the Collaborative Design Workshop the Morphological Overview was loose introduced as a Morphological Overview to the practitioners in the CD teams. The results of the analysis of the workshops executed clearly indicate the supportiveness of the tool by Architects directly after the introduction of the tool. Architects also show to be lazzards in terms of Rogers (1983, 1995) concerning the full adoption of the tool. After using it for the first time they seem to get less interested in using the tool.

All over 88% of the CD teams used the Morphological Overview in the different Design Task Settings and adopted it the first time. The practitioners used the Morphological Overview to notate the different types of object- and realization-knowledge that was relevant to the Design Task; in average more than half of the practitioners used the MO (56%). Comparing Architects and Contractors; about 76% of the Architects (13 out of 17; 76%) Architects used the MO and about one third (6 out of 17; 35%) of the Contractors used the MO for Design Task related notations. Overall observation is that more than 50% of all notated function-types and related sub-solutions which are generated by the teams in the design process are also notated in the Morphological Overview. Although in the development and detailing of the Design Task more sketches where used for notating object- and realization-knowledge compared to notations in the Morphological Overview, the step-by-step introduction of the Morphological Overview was positive for the notated realization-knowledge contributed by the Contractors.

A majority of the interviewed practitioners is also positive about the Morphological Overview for use in practice and education, although until now the majority of the interviewed practitioners did not use the Morphological Overview in their own practice.

Results of the Improved Research Analyses Protocol for RQ9

Based on the results about the use of the Morphological Overview (MO) in general, the next step is to refine the specific of the MO to the various CD teams and its practitioners. The main question is *what* knowledge (object- and realization-knowledge) was used in the MO *who* (Architect or Contractor) related to the Design-Task. The focus is on the contributions by the practitioners of realization-related function-types to view their role in the DWS and in the collaboration in the teams. An example of this analysis for RQ9 is presented in Appendix 12.6. (Example 7, page 180).

1. Results of CD Team contributions in the Morphological Overview

The first overview is that of the average contributions by the CD teams in the different Design Task Settings as an average of DWS 01 and DWS 02. These are the results of the analysis MAF3 which are presented in Appendix 10 and the corresponding overviews in Figures 10.13 and 10.14 (page 122). In the MAF3 those function-types and sub-solutions related to object- and realization-knowledge are notated with coding in these MAF3. Notated function-types and sub-solutions in the MO are though part of all notated function-types and sub-solutions in total per Design Task Setting, and differ per Design Task Setting.

The results which are presented in Figure 75 are for DWS Total and the average of DWS01 and DWS02, for notated object- and realization-knowledge in the MO. The average notated items in the MO are out of the average total notated items per Design Task Setting. The percentages of these results between brackets. The table in Figure 75 is related Figure 72 (page 154) which is used to answer RQ8 related to the use of the MO. The results of DWS Total in Figure 67 (page 146) correspond with the results Total in the Figure 75. Figure 75 gives a more detailed result on the knowledge-types with the focus on realization-knowledge.

KNOWLEDGE-TYPE	SOLUTION-TYPE	TASK 2 MO1 / Y1 B5, B6, B7, B9, B10 (6)	TASK 3 MO1 / X2 C1, C2, C3 (6)	TASK 3 MO2 / Y2 C5, C6, C7, C8 (5)
REALIZATION	FUNCTION-TYPES	5 out of 6,5 (77%)	6 out of 9,5 (63%)	6,8 out of 8,2 (83%)
	SUB-SOLUTIONS	39 out of 174 (22%)	35 out of 159 (22%)	42 out of 156 (27%)
OBJECT	FUNCTION-TYPES	9,5 out of 11,5 (83%)	6 out of 9 (67%)	5,6 out of 11,6 (48%)
	SUB-SOLUTIONS	83 out of 174 (48%)	42 out of 159 (26%)	34 out of 156 (22%)
TOTAL	**FUNCTION-TYPES**	**14,5 out of 18 (81%)**	**12 out of 18,5 (65%)**	**12,4 out of 19,8 (63%)**

Figure 75 DWS Total Teams; overview of notated object- and realization-knowledge in the Morphological Overview (MO).

Compared with the overview of all notated function-types by the teams of Figure 67 (RQ6, page 136), for the Design Tasks where the MO was loose introduced, in all Design Task Settings the average percentage notated function-types which are also notated in the Morphological Overview is lower, except for T2 MO / Y1 object-related (72% < 81%). This comparison gives the result that in group Y1 task 2 MO1, compared to the other Design Task Settings the most amounts of function-types and sub-solutions which were notated also were notated in the MO. The second comparison between Figure 67 and Figure 75 is on Design Task Settings. For the situation in Figure 67 in group Y as well as in group X was an increase of notated function-types in the subsequence Design Task Setting. This with a more positive tendency in group X compared to group Y. For the situation in Figure 75 on notated function-types in the MO the tendency is different. In group Y there is a decrease of notated function-types in the MO (Y1: 81%, Y2: 63%). Although the notated function-types in group X2 task 3 MO1 are lower compared to the Design Task Setting where the MO was also first loose introduced (Y1), the score in group X2 is slightly higher compared with group Y2 task 3 MO2. This gives the first indication as result of these analyses on team-level. Although there is an increase of notated function-types overall in group Y, there is a negative tendency for notated function-types in the MO in this group, compared with group X.

When comparing the Design Task Settings related to the notated items in the MO of Figure 75 the following results can be viewed. In total on notated function-types in average group Y1 task 2 MO1 (81%) has the highest score compared to group X2 task 3 MO1 (65%) where the MO was also introduced for the first time. The score is also higher compared to the Design Task Setting where the MO was introduced for the second time, group Y2 task 3 MO2: 63%.

More in detail with the focus on the knowledge-types in general more than 48% of the function-types which were notated were also notated in the MO. Of the notated sub-solutions in general always more than 22% were also notated in the MO. The highest score for notated function-types in the MO is in group Y1 task 2 MO1 (83% object-related function-types) and group Y2 (83% realization-related function-types). The highest score for notated sub-solutions in the MO is in group Y1 task 2 MO1 (48% object-related sub-solutions). When focusing on contributions of realization-knowledge in the Design Task Settings group X2 task 3 MO1 has the lowest score; 63% function-types and 22% sub-solutions in average notated in the MO. In group Y for both notated realization-related function-types as sub-solutions there is an increase. Function-types realization-related, Y1: 77%, Y2: 83%. Sub-solutions realization-related, Y1: 22%, Y2: 27%. For notated object-related function-types and sub-solutions there is an opposite tendency compared to the situation with the focus on realization-related items. For this situation group Y gives a negative tendency compared to group X2 task 3 MO1.

2. Results of notated individual contributions in the Morphological Overview

The influence of the MO on the individual level is derived from the individual notated object- and realization-knowledge through sub-solutions in the MO. This is the refined step derived from the outcomes of the analysis of the Video Observation Format (VOF) which are presented in detail in Appendix 11 (page 124 – 144). From the average notated object- and realization-knowledge in reference overviews per Design Task Setting are presented and summarized in tables and graphs. The final overviews in Appendix 11 are presented on pages 143 and 144 in Figures 11.19, 11.20 and 11.21. Figure 11.21 is used for the results in this paragraph as Figure 76 and corresponding graphical representation in Figure 77. This first analysis is followed by two analyses for more detailed views on the influence of the MO and the individual contributions. Second analyses is for the situations where both Architect and Contractor use notations in the MO. Third analysis is for those situations where both Architect and Contractor notate realization-knowledge in the MO.

First analyses:

Related to the notated items in the MO only those settings where the MO (Y1, X2 and Y2) was introduced give these results. Therefore setting X1 (without MO) is not part of the overviews of Figure 76 and 77 and also not part of the comparisons related to the MO. In Figure 76, page 151, for each practitioners-type Architect or Contractor per Design Task between brackets the number of participants which used the MO is notated. All results in Figure 76 are average notated object- and realization-related items by Architect and Contractor, between brackets the corresponding percentages per knowledge-type.

PARTICPANT TYPE	KNOWLEDGE-TYPE	TASK 2 MO1 / Y1 B5, B6, B7, B9, B10 (6)	TASK 3 MO1 / X2 C1, C2, C3 (5)	TASK 3 MO2 / Y2 C5, C6, C7, C8 (4)
ARCHITECT	REALIZATION	7,3 (74%)	5,3 (50%)	13,5 (88%)
	OBJECT	20,2 (79%)	8,6 (67%)	8 (76%)
TOTAL ARCHITECT		**27,5 (78%)**	**13,9 (59%)**	**21,5 (83%)**
CONTRACTOR	REALIZATION	2,5 (26%)	5,2 (50%)	1,8 (12%)
	OBJECT	5,3 (21%)	4,3 (33%)	2,5 (24%)
TOTAL CONTRACTOR		**7,8 (22%)**	**9,5 (41%)**	**4,3 (17%)**

Figure 76 DWS Total Contributions Practitioner-type in MO: average notated object- and realization related function-types and sub-solutions in the MO.

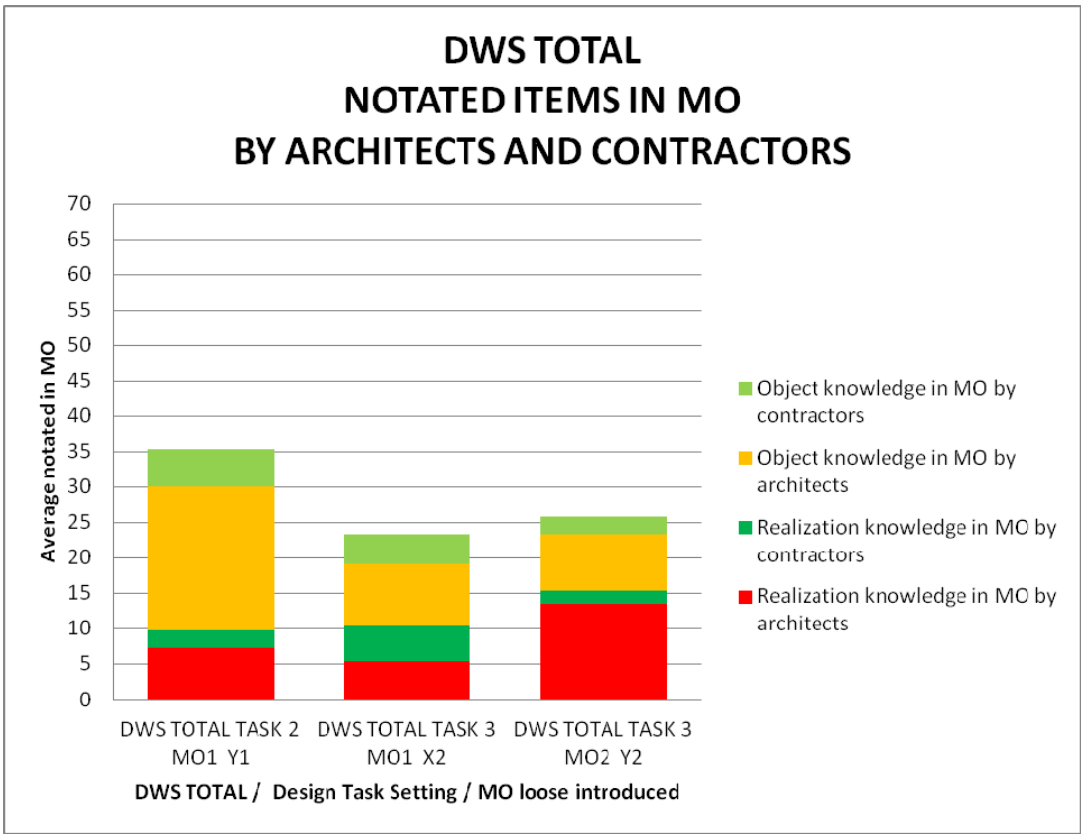


Figure 77 DWS Total Contributions Practitioner-type in MO: average of the notated object- and realization related function-types and sub-solutions in the MO, graphical representation.

Figure 76 and Figure 77 show also the influence of the MO on the contributions of the different practitioners, related to the order in which the MO is introduced. The results will be presented from the perspective of group X, Task 3 MO1 (X2). This is the Design Task Setting with Task 2 without the loose introduction of the Morphological Overview. In desgin-task setting group Y (Task 2 MO1; Y1 and Task 3 MO2; Y2) the MO is loose introduced in both Desgin Tasks.

Overall view shows that in all Design Task Settings the teams could use the MO for interaction and exchange of the different knowledge-types.

More in detail it can be observed that in Design Task Setting group X (X2 Total: Architects 13,9, Contractors 9,5) is more balance in the contributions of the Architects and Contractors in notations in the MO compared with both design-tasks in group Y. In group Y1 task 2 MO1 Contractors notate about 22% of all notated items in the MO and in group Y2 task 3 MO2 about 17% in the MO, compared with 41% which is notated by the Contractors in group X2 task 2 MO1. With the focus on realization-related items notated in the MO the Architect notates more compared to the Contractor and has the highest score on notated realization-related items in group Y. In group Y the Contractor has a low score compared to the Architect of notated realization-knowledge; about 26% in group Y1 task 2 MO1 and 12% in group Y2 task 3 MO2. This Design Task Setting is not positive for the contributions of the Contractor compared to Design Task Setting X2 task 2 MO1, related to notated object- and especially notate realization-related items. In group X2 task 2 MO1 the Contractor in average notates about 33% object-related items and about 50% of the realization-related items.

Another comparison can be made with the situation where all notated items are viewed (RQ6: Figure 68, page 149) related to the individual contributions in the MO (group Y1, X2, Y2). Overall the score of the Contractors for notated realization-knowledge is higher in Figure 68 compared with Figure 76 (page 150), except for group X2 task 2 MO1. For group X2 task 2 MO1 there is a increase of notated

realization-related knowledge comparing the situation with sketches and MO compared with the situation when only notated in the MO. Comparing group Y when with notated realization knowledge in sketches and MO with the situation when only notated in the MO, Architects notate even more items in average. Figure 68: Architects, realization-knowledge, Y1: 82%, Y2: 85%. Figure 76: Architects, realization-knowledge in MO, Y1: 74%, Y2: 88%. For the contributions of the Contractor in group Y there is a contrary tendency compared to Architects. Figure 68 (page 149): Contractors, realization-knowledge, Y1: 18%, Y2: 15%. Figure 76: Contractors, realization-knowledge in MO, Y1: 26%, Y2: 12%. In both situations group X2 task 2 MO1 is the most positive for realization-related knowledge notated by Contractors. Figure 68: Contractors, realization-knowledge, X2: 44%. Figure 76: Contractors, realization-knowledge in MO, X2: 50%. This gives another indication that the Design Task Setting starting with a traditional setting without MO followed by first introduction of the MO is most positive for the contributions of the Contractors.

Second analyses: situations where both Architect and Contractor used notations in the MO.

With the use of the analyses from the VOF and the VIF, as presented in Appendix 11 (page 124 – 144) a more specific view on the use of the MO can be determined: those teams where both Architects and Contractors use the MO (Figures 11.1 to 11.6., page 125 – 130). Of the 15 teams which used the MO, 4 teams could be selected where both Architects and Contractors used the MO: DWS02 Task 2, Teams B6 and B1, group Y1, MO1 (Figure 11.2, page 126); DWS01 Task 3, Team C3, group X2, MO1 (Figure 11.3, page 127) and DWS02, Task 3, Team C1, group X2, MO1 (Figure 11.4, page 128). An overview of the corresponding results of these teams are presented in Figure 78 and Figure 79 .

PARTICPANT TYPE	KNOWLEDGE-TYPE	DWS02 TASK 2 MO1 / Y1 B6	DWS02 TASK 2 MO1 / Y1 B10	DWS01 TASK 3 MO1 / X2 C3	DWS02 TASK 3 MO1 / X2 C1
ARCHITECT	REALIZATION	0 (0%)	3 (8%)	8 (19%)	2 (10%)
	OBJECT	2 (8%)	12 (31%)	22 (54%)	1 (5%)
TOTAL A		**2 (8%)**	**15 (39%)**	**30 (73%)**	**3 (15%)**
CONTRACTOR	REALIZATION	7 (27%)	8 (21%)	10 (25%)	3 (15%)
	OBJECT	17 (65%)	15 40%)	1 (2%)	14 (70%)
TOTAL C		**24 (92%)**	**23 (61%)**	**11 (27%)**	**17 (85%)**

Figure 78 DWS Total: Contributions of teams where both Architects and Contractors used the MO.

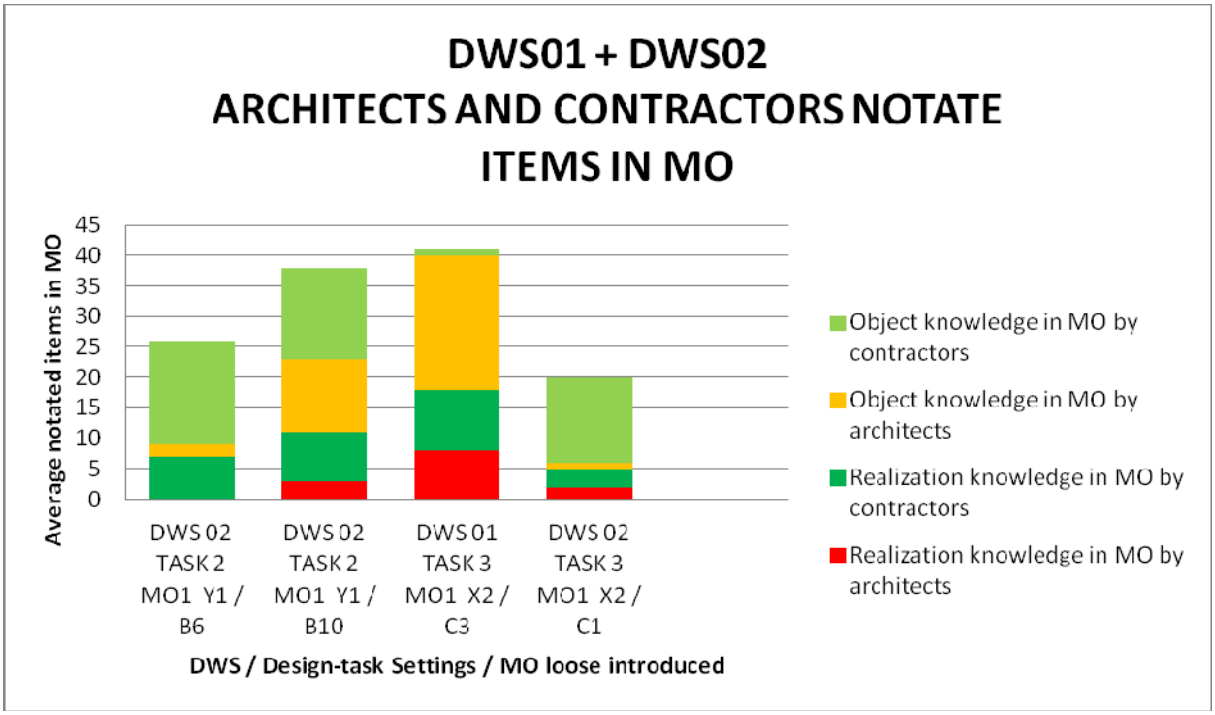


Figure 79 DWS Total: Contributions of teams where both Architects and Contractors used the MO, graphical representation.

First aspect of this result is related to the Design Task Settings in which the teams operated. All teams where both Architect and Contractor used the MO are those Design Task Settings where the MO was first loose introduced. Second aspect is related to the total number of teams which used the MO (RQ9), which is 15 teams. In 4 (27%) out of 15 teams both practioner-types where using the MO. In all other teams the Architect or the Contractor used the MO. Although not a positive result related to the criterium of 50% or more use of the MO, the result is encouraging. There are 2 teams out of 15 viewed where the Contractor was the practitioner which used the MO and the Architect not.

The third aspect is the view on contributions of object- and realization knowledge by Architects and Contractors in these teams (Figure 78). In all selected teams except team C3, DWS01, Taks 3, group X2, MO1, the Contractors notated the most function-types and sub-solutions in the MO. The scores of their notated items is between 61% and 92%, which is a positive result. With the focus on notated realization-related function-types and sub-solutions in the MO, the Contractors have also a positive score in all selected teams.

The results of this second analyses give positive indications about the fact that when the MO is loose introduced to Architects and Contractors in a collaborative setting they work collaboratively on the design task by interaction and knowledge exchange.

Third analyses: those situations where both Architect and Contractor notate realization-knowledge in the MO.

The most optimum situation for collaboration between Architect and Contractor is when both practitioner-types notate realization-related function-types and sub-solutions working collaboratively on a design task using the MO. This last step is derived from the second analyses and the teams selected. Figure 75 shows that in one of the four selected teams the Architect did not notate realization-related items. In all other teams both Architect and Contractor notated realization-related items in the MO; this is 20% of the teams which used the MO. Figure 80 and 81 show the results for these teams.

PARTICPANT TYPE	KNOWLEDGE-TYPE	DWS02 TASK 2 MO1 / Y1 B10	DWS01 TASK 3 MO1 / X2 C3	DWS02 TASK 3 MO1 / X2 C1
ARCHITECT	REALIZATION	3 (27%)	8 (44%)	2 (40%)
CONTRACTOR	REALIZATION	8 (73%)	10 (56%)	3 (60%)

Figure 80 DWS Total: Contributions of teams where both Architects and Contractors used the MO and notated realization-knowledge in the MO.

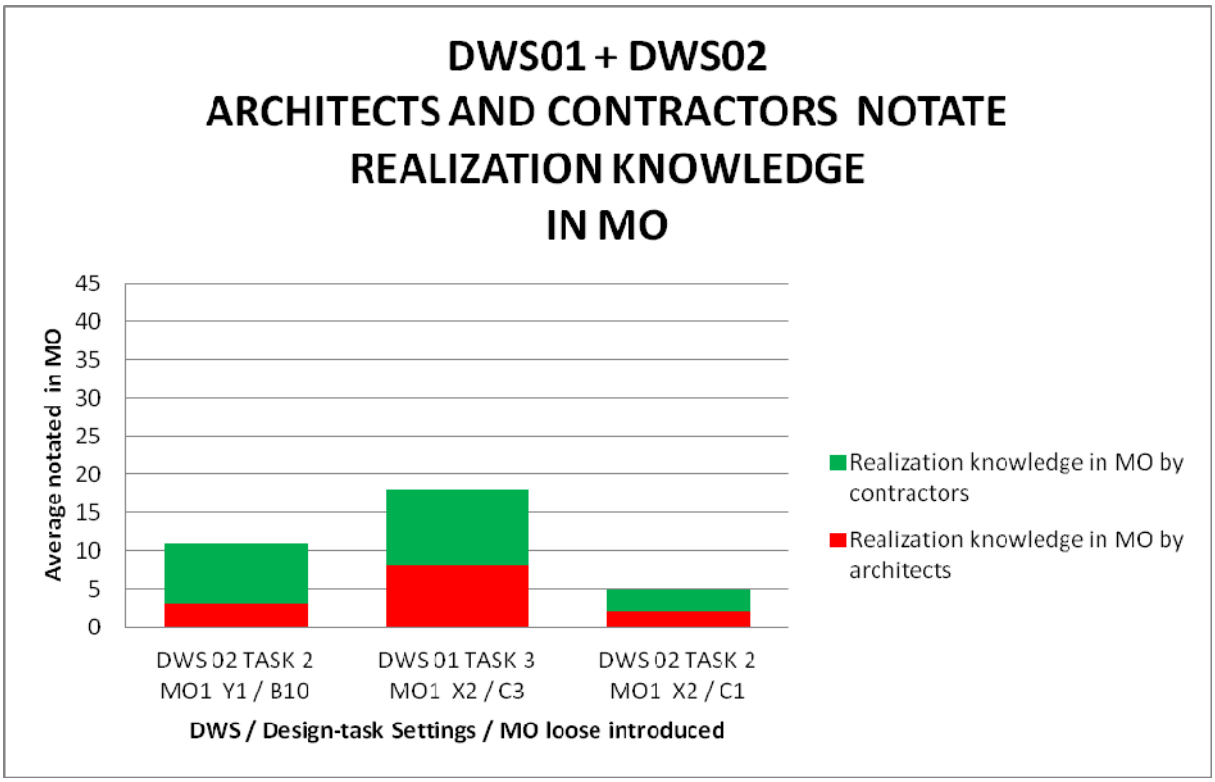


Figure 81 DWS Total: Contributions of teams where both Architects and Contractors used the MO and notated realization-knowledge in the MO, graphical representation.

Figure 81 shows that in those teams where both Architects and Contractors could notate realization-related function-types and sub-solutions, the Contractor had a positive role in the collaboration and contributions made. In all three teams the contribution of the Contractor was more than 56%.

These results give a positive indication for the role of the Contractor working with the Architect on a specific design task with the MO. The most positive situation is the situation where first Architect and Contractor work in a more traditional setting followed by a setting where the MO is loose introduced (group X).

3. Answer for RQ9

The following tendencies can be observed for RQ9. On team level the three main tendencies areas follows. First: in group Y1 task 2 MO1 and Y2 task 3 MO2 notated most of the function-types and sub-solutions in the MO compared to teams in group X2 task 2 MO1. Second, the teams in group Y1 task 2 MO1 notate overall the most object- and realization-related function-types: 81%. Third: teams in group Y2 task 3 MO2 notate the most realization-related function-types: 83%. Teams in group Y1 task 2 MO1 contribute the most realization-related sub-solutions: 48%.

On individual level four tendencies can be viewed. First: in group X2 task 2 MO1 the most balanced contributions in the MO are made by Architects (59%) and Contractors (41%) compared to group Y1 and Y2. Second: related to the contributions by the Contractor of realization-related function-types and sub-solutions, group X2 task 2 MO1 is most optimum compared to group Y1 and Y2, the Contractor contributes 50% realization-knowledge in the MO. Third: in 27% (4 out of 15) teams both Contractor and Architect use the MO. All the teams where in a Design Task Setting where the MO was loose introduced for the first time (group Y1 and X2). The contributions in these teams of Contractors where all more than 61%. Fourth: in 20% of 15 teams who used the MO, both Architect and Contractor notated realization-related function-types and sub-solutions in the MO. Two of the three teams are in group X2 task 2 MO1. In all three teams the Contractor notated more than 56% of this realization-knowledge.

These results are a confirmation of the tendency related to all notated function-types and sub-solutions as well in sketches as in the MO (RQ6). With these results now RQ9 can be answered.

RQ9 *When used did the Morphological Overview allow for the exchange and structuring of knowledge between the practitioners?*

A RQ9 Using the Collaborative Design Workshop, the practitioners are free to use different types of communication to contribute and develop the object- and realization knowledge needed to fulfill the Design Tasks. In the variety of available communication types the Collaborative Design Workshop introduces a new Morphological Overview to the majority of the practitioners in a Practice Setting and a complex Design Task. This Morphological Overview has the purpose to encourage the exchange and structure of object- and reallization knowledge by Architects and Contractors in collaboration as the basis for an Integral Design.

By using the Video Observation Format and Video Interaction Format in detail the influence of the Morphological Overview in the exchange and structuring of object- and realization-knowledge during the design process was observed and analyzed. What can be observed is that in average in all design-settings the Morphological Overview allowed for exchange and structuring of knowledge between the practitioners, although three remarks have to be made. First; between 48% and 58% of the function-types reference-list was average notated in the Morphological Overview. Second, in one fifth of the teams who used the MO both Architects and Contractors notated realization-knowledge in the MO. the Design Task Setting were the Morphological Overview was introduced after the Design Task Setting without the introduction of the Morphological Overview (group X2) is the most effective way for contributions in general and realization-knowledge and Contractor-contributions in particular.

3.5 OVERVIEW OF ALL ANSWERS TO RESEARCH QUESTIONS

The main Goal of Descriptive Study 2 is to test the key-components and finalized research improvements for the Goals in the Definitive Collaborative Design Workshop. Part one of this testing was done on the basis of Research Questions related to the four key-components: Team, Task, Setting and Tool. These answers to the Research Questions could be given on the basis of the results of the Goals in the Descriptive Study 2. This part two consists of the results of the testing of the finalized research improvements related to the key-components for managing, observation, analyzing and evaluation formats. The outcome of this Descriptive Study on the basis of these two parts is the Technological Design, presented in the next section 3.6.

Part one is presented with an overview of all Research Questions and related answers.

RQ1 *What type of knowledge should the competent Architect, roofer and installer possess?*

A RQ1 As confirmed by the literature review and within the context of the collaborative setting for roof design the Architect represents 'object knowledge' for designing, and the Contractor (roofer / installer 'realization knowledge' for the execution of the design. The Architect, having a specific background, tends towards 'reflective practice' (Schön 1983) in developing the design-problem, which is in an iterative process. The Contractor in contrast, tends towards 'rational problem solving' as Simon (1973) explains, which is a linear and reactive process is in fact. The explicitly used knowledge by the different practitioners is necessary for an effective use and sharing of knowledge during the design-process.

RQ2 *When and how should this knowledge be exchanged ideally within a Collaborative Design Team?*

A RQ2 ***When***

Process knowledge can be exchanged most successfully in the preliminary stages when actors need to make creative decisions about the design in order to reduce uncertainty and narrow the solution space; this process requires collaboration in these early phases.

A RQ2 ***How***

Knowledge exchange between the practitioners of the Collaborative Design teams being studied should be done via a face to face medium to avoid 'noise' and to stimulate collaboration and interaction.

RQ3 *What factors hindered the success of the Case Study projects?*

A RQ3 In summary, the three Case Studies suffered mainly from the same two primary causes. These main causes identified as a lack of competence, poor knowledge- exchange and structuring, which led to significant failures in all three projects. In order to seek workable remedies for these causes of failure, a further literature review was conducted.

RQ4 *What are the necessary key- components of the Technological Design?*

A RQ4 The necessary key-components that are assumed to be most important in the Technological Design are as follows: Design Task; Collaborative Design Team; Practice Setting; Morphological Overviews.

RQ5 *Were the tasks sufficiently complex to require collaboration between the practitioners?*

A RQ5 To solve complex Design Tasks, different types of knowledge are needed which have to been put forward and developed by different types of practitioners. This knowledge is discussed and notated as function-types and related sub-solutions to get insight into the complexity and to generate possible solutions in collaboration. Through the analyses within the research project the different types of notations, the used amount of function-types and sub-solutions and personal questionnaires show that the Collaborative Design Workshop is a productive setting for the different practitioners to work on such complex design tasks.

RQ6 *Did both types of practitioners succeed in contributing realization knowledge?*

ARQ6 To fulfill the complex Design Tasks specific object- and realization-knowledge needs to be contributed and developed by the different practitioners within the Practice Setting as the basis of Integral Roof Designs. These specific contributed function-types of knowledge, as represented by the reference-list, have to be applicable to the Design Task. They are sufficient when no realization-knowledge is missing which is needed to design and realize an Integral Roof Design.

The Video Observation Format, developed in WS04 and WS05, and Video Interaction Format, developed in WS05, were used to determine the different types of contributed object- and realization knowledge of Architects and Contractors in the Collaborative Design teams. By using the Collaborative Design Workshop overall the individual practitioners made design-task contributions, although in such teams it is difficult to generate sufficient, realization-knowledge, contributions for an Integral Design for roofs as a solution to a complex task in the given time-frame.

RQ7 *Did the face-to-face setting provided by the workshop allows collaboration between the practitioners working on the design task?*

ARQ7 Practitoners working on complex design tasks within CD teams in the Collaborative Design Workshop are challanged to use different types of communication and represenation to put forward, discuss and develop specific object- and realization-knowledge. Communication and representation are effective when the sender and receiver are in interaction with each other about the design task.

With the Video Interaction Format that was used and tested in the research project the differerent types of communication could be determined in the face-to-face setting between the different practitioners within the design-teams. The results show that all over a variety of communication types (speech, sketch, MO) were used by and between the different designers and Contractors. Although the Architects are the most active practitioners in notations, the step-by-step introduction of the Design Task, CD Team and Morphological Overview gives the Contractors an improved Practice Setting to collaborate.

RQ8 *Did loose introduction of the Morphological Overview lead to acceptance of the tool?*

ARQ8 In the Collaborative Design Workshop the Morphological Overview was loose introduced as a Morphological Overview to the practitioners in the CD teams. The results of the analysis of the workshops executed clearly indicate the supportiveness of the tool by Architects directly after the introduction of the tool. Architects also show to be lazzards in terms of Rogers (1983, 1995) concerning the full adoption of the tool. After using it for the first time they seem to get less interested in using the tool.

All over 88% of the CD teams used the Morphological Overview in the different Design Task Settings and adopted it the first time. The practitioners used the Morphological Overview to notate the different types of object- and realization-knowledge that was relevant to the Design Task; in average more than half of the practitioners used the MO (56%). Comparing Architects and Contractors; about 76% of the Architects (13 out of 17; 76%) Architects used the MO and about one third (6 out of 17; 35%) of the Contractors used the MO for Design Task related notations. Overall observation is that more than 50% of all notated function-types and related sub-solutions which are generated by the teams in the design process are also notated in the

Morphological Overview. Although in the development and detailing of the Design Task more sketches where used for notating object- and realization-knowledge compared to notations in the Morphological Overview, the step-by-step introduction of the Morphological Overview was positive for the notated realization-knowledge contributed by the Contractors.

A majority of the interviewed practitioners is also positive about the Morphological Overview for use in practice and education, although until now the majority of the interviewed practitioners did not use the Morphological Overview in their own practice.

RQ9 *When used, did the Morphological Overview allow the exchange and structuring of knowledge between the practitioners?*

A RQ9 Using the Collaborative Design Workshop, the practitioners are free to use different types of communication to contribute and develop the object- and realization knowledge needed to fulfill the Design Tasks. In the variety of available communication types the Collaborative Design Workshop introduces a new Morphological Overview to the majority of the practitioners in a Practice Setting and a complex Design Task. This Morphological Overview has the purpose to encourage the exchange and structure of object- and reallization knowledge by Architects and Contractors in collaboration as the basis for an Integral Design.

By using the Video Observation Format and Video Interaction Format in detail the influence of the Morphological Overview in the exchange and structuring of object- and realization-knowledge during the design process was observed and analyzed. What can be observed is that in average in all design-settings the Morphological Overview allowed for exchange and structuring of knowledge between the practitioners, although three remarks have to be made. First; between 48% and 58% of the function-types reference-list was average notated in the Morphological Overview. Second, in one fifth of the teams who used the MO both Architects and Contractors notated realization-knowledge in the MO. the Design Task Setting were the Morphological Overview was introduced after the Design Task Setting without the introduction of the Morphological Overview (group X2) is the most effective way for contributions in general and realization-knowledge and Contractor-contributions in particular.

3.6 HYPOTHESES AND MEASURABLE SUCCESS CRITERIA

Derived from the answers to the Research Questions and related results the Hypotheses can be denied or confirmed. This is done using the Measurable Success Criteria as formulated in Chapter 3.1.3 (page 49).

Hypothesis 1. *The Collaborative Design Workshop leads to interaction and knowledge exchange between the practitioners involved.*

With the percentages of different communication types (speech, sketch, MO) and notated object- and realization knowledge by the different practitioners in the Definitive Collaborative Design Workshops, interaction and knowledge exchange could be determined (Measurable Success Criteria 1). This determination was possible through the use of the developed observation, analyzing and evaluation formats; the Video Observation Format (VOF), Video Interaction Format (VIF), Morphological Analyzing Format (MAF) and Evaluation Formats (EF). By applying these formats in the two DWS additionally the key-components could be tested and related Research Questions (RQ) answered. With these outcomes Hypothesis 1 can be confirmed.

Hypothesis 2: *The Collaborative Design Workshop stimulates interaction and knowledge exchange for Integral Roof Designs by incorporating realization knowledge.*

In the different Design Task Settings of the DWS interaction and knowledge exchange between Architects and Contractors could be determined on team-level as well as participant-level. Also could be observed and analyzed that specifically realization knowledge was used, contributed and explicitly notated by both participants in the different Design Task Settings of the DWS. (Measurable Criteria 2) Additionally the use of the Supportive Design Tool – the Morphological Overview – showed to be supportive to the involved practitioners to put forward and structure object- and realization-knowledge. These outcomes could determined by the use of the VOF, VIF, MAF and EF in the Improved Research Analyses Protocol, combined with the testing of the key-components Task, Team, Setting and Tools by answering the related RQ. Hypothesis 2 can therefore be confirmed on the bases of these outcomes.

3.6.1 OVERVIEW DRM STAGES, THE CORRESPONDING RESEARCH QUESTIONS AND GOALS

By using the DRM framework the Research Questions were answered and the Goals per stage where met. On the basis of these two outcomes finally the Hypothesis could be confirmed. In Figure 82 the overview of this DRM framework is presented.

The Technological Design, as outcome of the Descriptive Study 2 the research project can now be finalized. In the next section the Technological Design is presented. In the final Chapter the conclusions will be presented. Through reflection on these conclusions recommendations for future research will finally be formulated.

	DRM Stage	Research Question(s)		Goals
1	**Research Clarification**	**RQ1**	*What type of knowledge should the competent architect, roofer and installer possess?*	Problem identification+answers RQ1-RQ2
		RQ2	*When and how should this knowledge ideally be exchanged within a Collaborative Design Team?*	Development of RQ3 and RQ4 Hypotheses and Measurable Success Criteria
2	**Descriptive Study 1**	**RQ3**	*What factors hindered the success of the Case Study projects?*	Problem is expressed in practice
		RQ4	*What are the necessary Key-components of the Technological Design?*	Key-components identification Development of: RQ 5-6-7-8-9
3	**Prescriptive Study**			Pre-Answers to: RQ 5-6-7-8-9 Research Improvements
	WS01S *Students workshop*			Determine if the setting encourage interaction Determine if Observation Format is suitable
	WS02 *Students workshop*			Development of alternative observation and analysis methods for the effects of use of the (loosely introduced) Morphological Overview Determine the effect of the use of the (loosely introduced) Morphological overview on knowledge exchange
	WS03 *In-company workshop*	**RQ5**	*Were the tasks sufficiently complex to require the collaboration between the practitioners?*	Evaluation of the analyses to determine the complexity of the Design Task; a quick-scan, the Functional Analysis, pre-defined questionnaires
		RQ7	*Did the face-to-face setting provided by the workshop allows collaboration between the practitioners working on the design task?*	Evaluate the use of the developed Quick-scan, the Observation format 2 and Morphological analysis format
	WS04 *Practitioners workshop*	**RQ6**	*Did both types of practitioners succeed in contributing realizations knowledge?*	Evaluate the use of the developed Video Observation Format and the Research Analysis Protocol
		RQ8	*Did loose introduction of the Morphological Overview lead to acceptance of the tool by the practitioners?*	Evaluate the adoption and use of: the Morphological Overview: Quick-scan, Morphological Analysis Format 3 (MAF3) and Pre-defined questionnaires
	WS05 *Practitioners workshop*	**RQ9**	*When used did the Morphological Overview stimulate for the exchange and structuring of knowledge between the practitioners?*	Evaluation of the effect of the use of the Morphological overview Evaluation of the use of: the Video Observation Format (VOF), the Video Interaction Format (VIF) Development and application of the Collaborative Design Workshop set-up Finalizing of Research improvements
4	**Descriptive Study 2** *Practitioners Workshop*	**Test RQ 5-9**		Answers to: RQ 5-6-7-8-9 Testing the Key-components and Research improvements in the Definitive Collaborative Design Verification of the Key-components and the analyzing tools: VOF, VIF, MAF3, and Evaluation Formats Evaluation of the Hypotheses and Measurable Success Criteria

Figure 82 DRM-stages with corresponding Research Questions and Goals.

3.7 THE TECHNOLOGICAL DESIGN: A COLLABORATIVE DESIGN WORKSHOP

In this section the model for the Collaborative Design (CD) Workshop is presented and the Protocol for the use of the model. The model (Figure 83) is the final result of the tests in the Definitive Collaborative Design Workshop (DWS). The model consists of a specific design for the two days workshop for which specific practitioners need to be invited; the workshop management is specifically explained because of the skills needed for the management and observation of the workshop activities, for the use of the observation, analyzing and evaluation formats. These formats are output of the research project and consist of the VOF (Video Observation Format), the VIF (Video Interaction Format), the MAF (Morphological Analyzing Format) and Evaluation Formats. For the analyzing of the generated observation information, using the VOF, VIF, MAF and Evaluation Formats, specific skills of the users are needed. In the scheme in Figure 83 the overview of the model is showed.

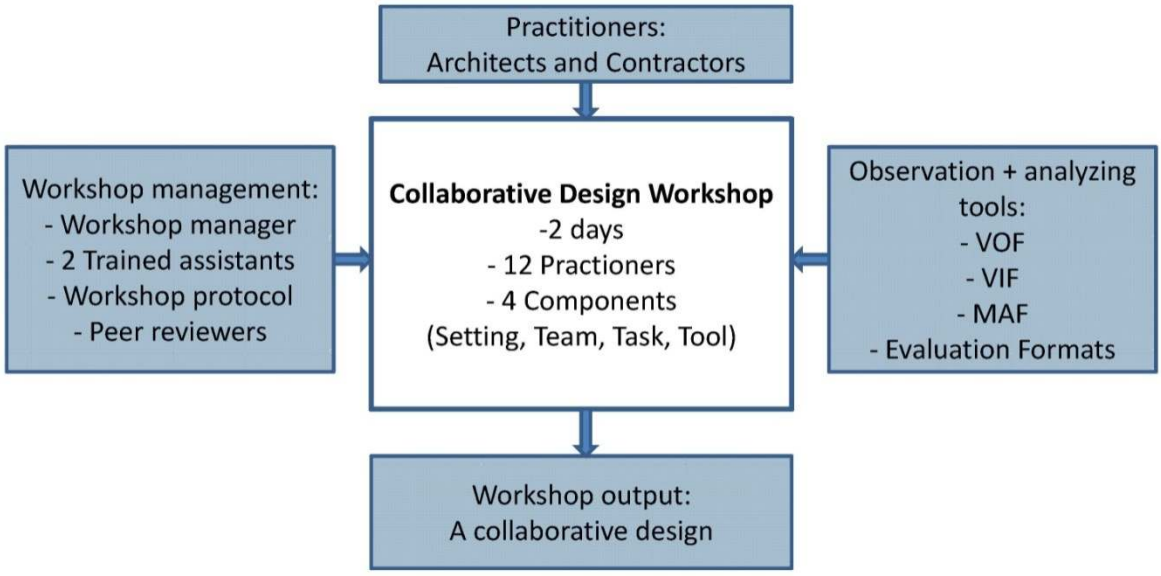


Figure 83 The model for the CD Workshop

Figure 84 on the next page shows the Organizing Structure for execution of the workshop from start to finish. In the next paragraphs, consecutively the organizing procedure, the workshop protocol, the observation protocol and functioning is described. The formats for stimulating and observing interaction and knowledge exchange (VOF, VIF and MAF) and the Evaluation Formats are described and how the workshop manager and the observation team should apply these tools. Also the steps, calculation and judgment on basis of the analyzing of the generated data is described and the competence of the peer reviewers.

In Part one the Protocol for the Collaborative Design Workshop is described. Part two describes the Protocol of the Workshop Observation Analysis - the VOF, the VIF, the MAF and the Evaluation Formats - and how you should apply the Result Analysis.

Organizing structure

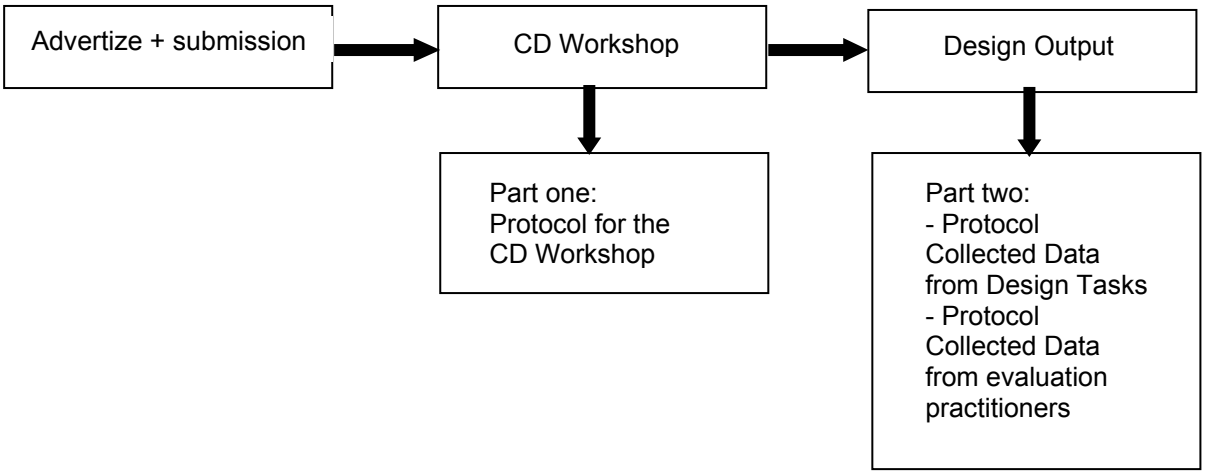


Figure 84 Organizing Structure

3.7.1 CD PROTOCOL PART ONE: ORGANIZING CD WORKSHOP

Organization and management:

To organize the CD Workshop the next four steps need to be followed:
1. Advertize the Workshop to the practitioners in close cooperation with the Professional Organizations related to the practitioner's knowledge domain. The advertisement should be entitled: *CD Workshop to support interaction and knowledge exchange for integral design*.

2. Submission for practitioners should be allowed if they have at least *10 year experience* in their practitioners-field. In each Workshop practitioners, with different education background will be working collaboratively in different phases of design and realization. Designers should have an academic level, f.i. a Master degree in Architecture and Contractors should have a technical engineering level of MBO. The submission need to be administrated by the Professional Organization, who is able to check the competences of the practitioner, in terms of: the type of practitioner, type of current job and number of years of experience.

3. A minimum of 6 practitioners, 3 of each discipline, is needed to execute the CD Workshop to be able to exploit the proposed setting for the workshop. This minimum number is needed to make it possible to change teams for each Design Task and for the selected use of the Morphological Overview (MO). So minimal 3 teams consisting each of 2 practitioners, one Architect and one Contractor, are needed. Each practitioner that takes part is given a number, in order of subscription. The practitioners change after executing a Design Task to other based on a pre-defined system with the subscription-numbers. One important remark has to be made: to be sure to have enough practitioners to organize the workshop more practitioners should be invited to the CD Workshop when practitioners sign out before applying the CD Workshop. Advice is to invite 8 practitioners at least.

The following guidelines need to be followed for executing the Workshop:

- The CD-Workshop needs to be managed by a workshop manager. This manager is someone who needs to have practical experience with training professionals in the construction industry and the executions of workshops. This experience is necessary for the following reasons, first: the practical aspects related to organizing the workshop for professionals and the professional organizations, second: aspects related to content of the subjects within the building industry which are part of the

workshop and third: to have insight of the relationship between the workshop-part and the analyzing part, the importance of the observation and data-collection.

- The workshop manager should have support of at least two trained assistants to form the organization and observation team. These assistants need to have design knowledge on academic level and be experienced in the execution of workshops. The use of the Morphological Overview, the Video Observation Format and the Video Interaction Format should be explained to the workshop manager and the trained assistants by the peer reviewers and if necessary trained in their use. These assistants will assist the manager during the CD Workshop to observe the activities and for all practical aspects for the Design Task (equipment, collect documents, collect questionnaires) and the Observation Tools (photographs and video-recordings). The trained assistants will also execute the interviews for the practitioners after 6-months.

- The analyzing and judgment concerning interaction and knowledge exchange and results of the design activities in the workshop needs to be executed by two peer reviewers These peer reviewers should have at least 10 years experience in the construction practice and experience with workshops for professionals. This broad experience is needed for two main reasons, first; aspects related to the content of the subjects within the building industry which are part of collaborative design and the competences of the practitioners, second: to interpret and judge the process of collaboration for design by interaction and knowledge exchange, the used function-types, sub-solutions. The peer reviewer has to manage all activities by using this protocol, including the use of the Morphological Overview (MO). He needs to judge the design output by using the analyzing Formats: the Video Observation Format, the Video Interaction Format, the Morphological Analysis Format and the Evaluation Formats.

PROTOCOL FOR THE CD WORKSHOP

The CD Workshop consists of four key-components that are described below: Team, Task, Setting and Tool. Each key-component has specific characteristics in content and how to organize.

I. Team: Each Design Team consists of two practitioners: an Architect and a Contractor. Each practitioner gets a number which corresponds with the order of subscription, which is randomly organized in a Design Team and in two separate groups: group X and group Y. For each new Design Task the teams are changed in order to organize a team which consists of practitioners that did not work together for another Design Task. Participants assigned to group X or Y will stay in this group during the CD Workshop.

II. Task: Each Design Task should be related to a practical and realistic situation from practice and related to the knowledge domains of the practitioner-types in the Design Team. The Design Tasks introduced should be comparable in type and difficulty of the subject and task. The time-frame available to work on the Design Task should work as a ‘pressure cooker’ and be equal for each Design Task: 1 hour.

III. Setting: The Design Setting should be organized in an agreeable and relaxing environment with sufficient working space for each Design Team consisting of two practitioners with different educational background. The observation team, consisting of trained assistants, is part of this setting. Sufficient space between each Design Team is needed to avoid noise and interference between the teams. There should be catering facilities: drinks and snacks, available for the practitioners and the management during the CD Workshop. Equipment for the Design Setting: A3-format sketching paper, writing blocks, writing / sketching-tools; no additional back-up knowledge systems (handbooks, data-bases, internet etc.). All documents need to be registered with Team-number and Design Task-number for the analyzing phase.

IV. Tool: The practitioners are introduced to the Morphological Overview (MO) by the manager of the Workshop. He/she needs to explain the purpose of the tool, the functioning of it, with specific examples, and finally how the tool needs to be used. No further introduction of the tool needs to be done to avoid a prescriptive use of the tool. It can be expected that the Practitioners use it as introduced or in their own way. The MO is explained further in the paragraph Lay-out of the Workshop and MO.

Equipment for the Observation: Digital photographs: of each team and produced documents, each 10 minutes. Video-recordings with sound: of each team and positioned with the focus on the working desk. Each video-tape and photograph-map should be documented with: CD Workshop-number, Design Task-number, and Team-number.

There are two additional support-scripts for the management of the CD Workshop: Protocol Appendix 1 (page 196); the Time Schedule for organizing the Workshop and Protocol Appendix 2 (page 197 – 198); Workshop Script.

PROGRAM OF THE CD WORKSHOP

The CD Workshop has a running time of 16,5 hours divided into 2 days with a break of 1 week in between:

Day 1	**date:**	**location:**
9.00 – 9.15 h.:		Introduction: aim and purpose of the first day Workshop
9.15 – 10.00 h.:		Lecture 1: on collaborative design
10.00 – 10.45 h.:		Lecture 2: innovation on sustainable energy and roofs
10.45 – 11.00 h.:		Coffee break
11.00 – 11.15 h.:		Introduction of individual practitioners to Design Task 1
11.15 – 12.15 h.:		Design Task 1 (individual)
12.15 – 13.15 h.:		Lunch
13.15 – 13.30 h.:		Introduction of the practitioners to Design Teams (XI.1, XI.2, XI.3, YI.1, YI.2,YI.3 to Design Task 2
13.30 – 14.30 h.:		Design Task 2 (team)
14.30 – 15.00 h.:		Coffee break
15.00 – 16.00 h.:		Presentation of results teams Design Task 2
16.00 – 17.00 h.:		Group evaluation on design task and team collaboration

Day 2

9.00 – 9.30 h.:	Introduction: aim and purpose of second day Workshop
9.30 – 10.30 h.:	Lecture 3: examples of innovative roofs in practice
10.30 – 11.30 h.	Introduction to the use of the Morphological Overview
11.30 – 10.45 h.:	Coffee break
10.45 – 11.00 h.:	Introduction of the practitioners to Design Teams (XII.1, XII.2, XII.3, YII.1, YII.2,YII.3 to Design Task 3
11.00 – 12.00 h.:	Design Task 3 (team) MO loose introduced
12.00 – 13.00 h.:	Lunch
13.00 – 14.30 h.:	Presentation of results of Design Task 3
14.30 – 15.00 h.:	Coffee break
15.00 – 16.00 h:	Group evaluation of day 2 and on the total workshop regarding: design tasks, team collaboration, and use of the MO
16.00 – 16.15 h.:	Individual evaluation of workshop by Questionnaire format on: design tasks, team collaboration, use of the MO
16.15 – 17.30 h.:	Informal and social contacts between practitioners and workshop organization

LAY-OUT OF THE WORKSHOP AND MORPHOLOGICAL OVERVIEW (MO)

The Figure 85.1 shows the Lay-out of the CD Workshop (CD Workshop) with the different steps, configuration of the team and the results.

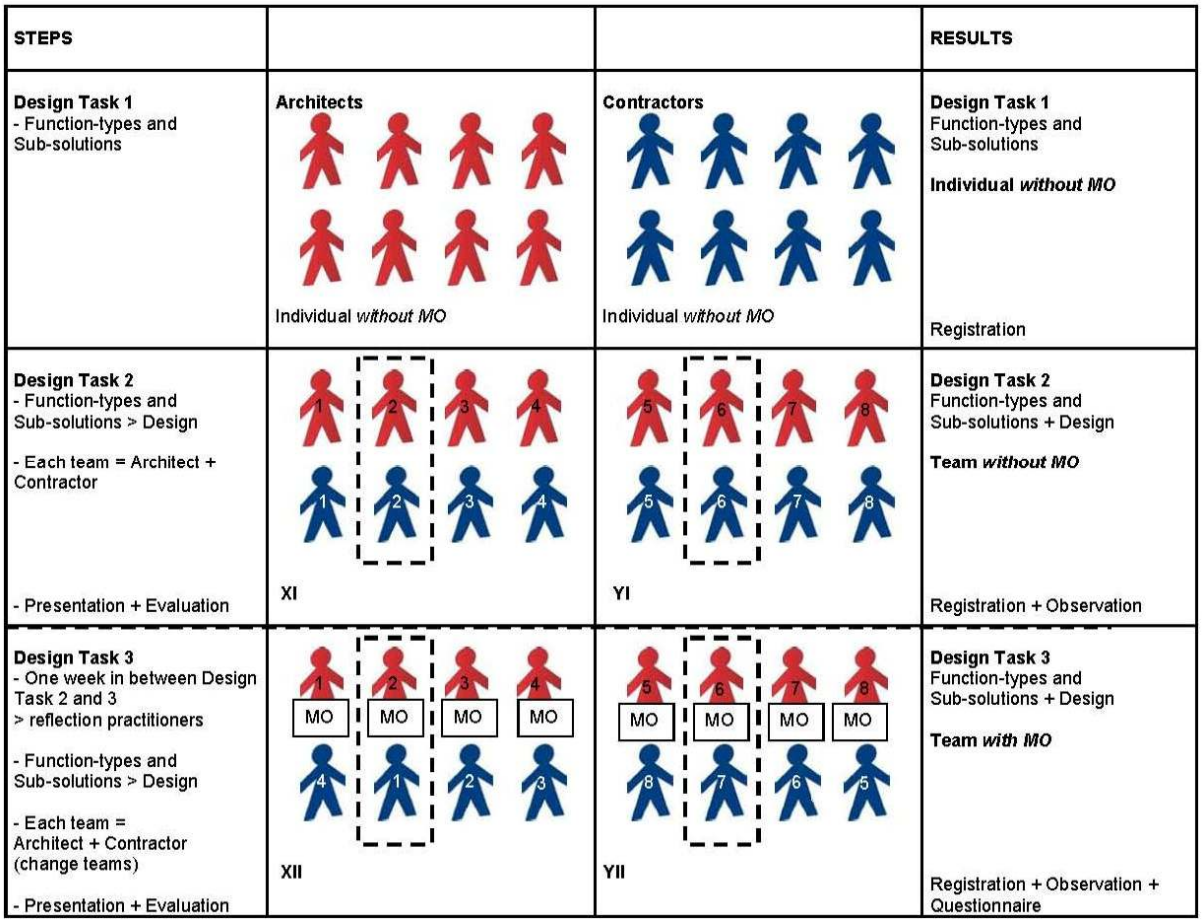


Figure 85.1 CD Workshop Lay-out – Protocol.

To organize the CD Workshop after the individual Design Task 1 the total group of assigned practitioners is split up in group X and group Y with an equal amount of practitioner-types to work in a Design Team. Each Design Team consists of two practitioners: an Architect and a Contractor. Practitioners assigned to a group stay in this group during the CD Workshop. Design Teams of group X and Y should work parallel on the same Design Task within the Lay-out as presented. For the next Design Task for teams the practitioners are changed for this team, to avoid working together with the same practitioner twice during the CD Workshop. There should be one week in between the Design Task 2 and Design Task 3 to facilitate reflection for the practitioners on the collaboration and the CD Workshop.

The scheme to organize the CD Workshop is presented in Figure 85.2 on the next page. This organization of the CD Workshop makes it possible to compare and evaluate within one CD Workshop two groups of participants related to interaction, knowledge exchange and use of the Morphologic Overview (MO).

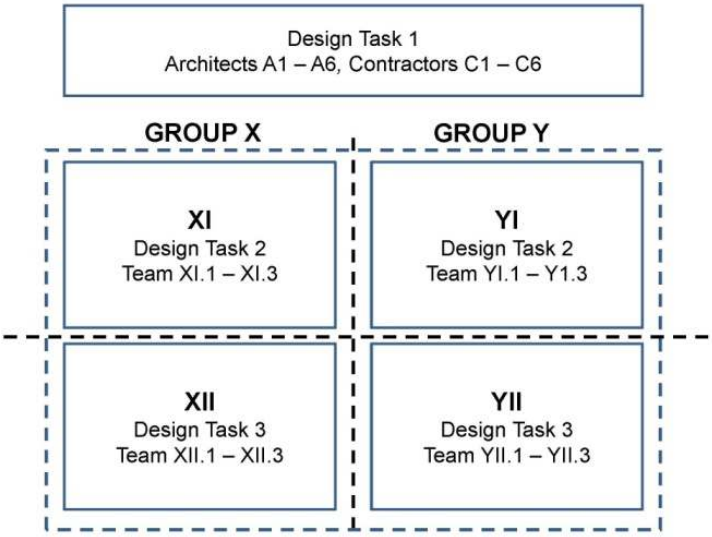


Figure 85.2 CD Workshop Scheme – Protocol.

The following notation-scheme is used for the different design tasks = team code:

- design task 1 (individual, without supportive tool MO): A*1-x*, C*1-x*
- XI: design task 2 (CD-team / Group X, without MO): XI.1 – XI.3
- YI: design task 2 (CD-team / Group Y, without MO): YI.1 – YI.3
- XII: design task 3 (CD-team / Group X, with MO1): XII.1 – XII.3
- YII: design task 3 (CD-team / Group Y, with MO2): YII.1 – YII.3

These schemes show that at least 6 Design Teams for one Design Task should be monitored, 3 Design Team per group. This implies at least 12 practitioners, 6 of each practitioner-type (Architect, Contractor). To reduce the risk of a shortage of available practitioners by not showing up, it is strongly recommended to invite 8 practitioners per type.

The Morphological Overview (MO) has the lay-out of a matrix: on the vertical axis of the matrix the required function-types of the design are given. On the horizontal axis the possible design sub-solutions for the function-types are given. The vertical listing is important for the practitioners to write down explicitly the essential aspects. These aspects must be incorporated in the design as function-types for the design to fulfill (Figure 86).

Sub-solutions → Function types ↓				

Figure 86 Lay-out of the Morphological Overview

3.7.2 CD PROTOCOL PART TWO: THE OBSERVATION-, ANALYSES AND -RESULT PROCEDURE

INTRODUCTION

For the observation analyses and the design result analyses the next two schemes are important to get an overview on the Protocol to follow. The first scheme shows the levels of comparison in observation and analyses (Figure 87), from a global comparison on Workshop-level (eg. WS 01 and WS 02) to a fine-grained comparison between practitioners (Architect and Contractor). These levels of comparison are organized with the following key-components: Team, Task, Setting and Tool. The comparisons are determined step by step and are related to the following aspects: knowledge interaction and knowledge exchange. These comparisons have the aim to give insight into: knowledge interaction through different communication types, knowledge exchange by the notated object- and realization-knowledge and the influence of the Morphological Overview as a Design Support Tool.

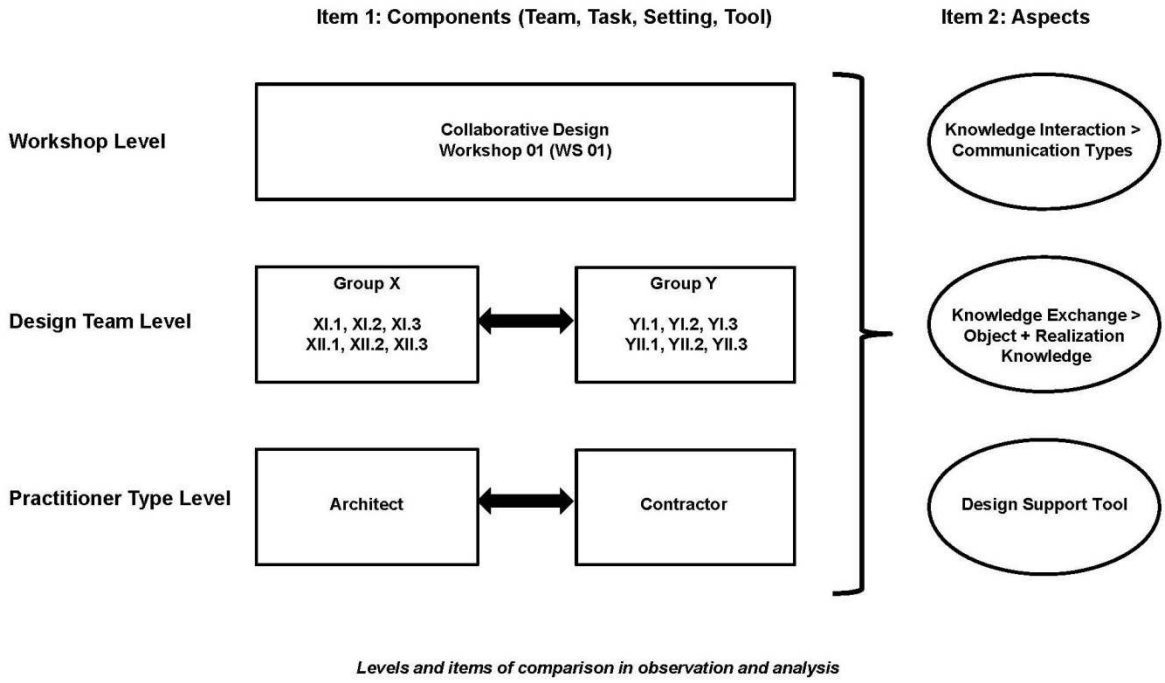


Figure 87 Levels and items of comparison in observation and analysis.

The second scheme as showed in Figure 88, next page, relates the aspects for comparison using the Video Observation Format (VOF), the Video Interaction Format (VIF) and the Morphological Analyzing Format (MAF) to observe and analyze the data generated; the video-recordings of the Design Task Settings of the CD Teams. The video-recordings need first to be observed and analyzed using the VOF, with a coded transcription. This gives insight in the *what, who, how* and *when,* related to the knowledge exchange and interaction between the practitioners of each team. With the outcome of this first analysis, the two other analyzing formats need to be used. First, the VIF and second, the MAF. The VIF focuses on the interaction between practitioners per CD-workshop, Design Team and Practitioners using the Tool and generates data concerning the interaction that takes place. The interaction concerns speech, sketch and the use of the Morphological Overview. The use of the MAF finally generates data about the knowledge exchange of the CD Teams.

Both schemes (Figure 87 and 88) you need to use for guidance throughout the Protocol.

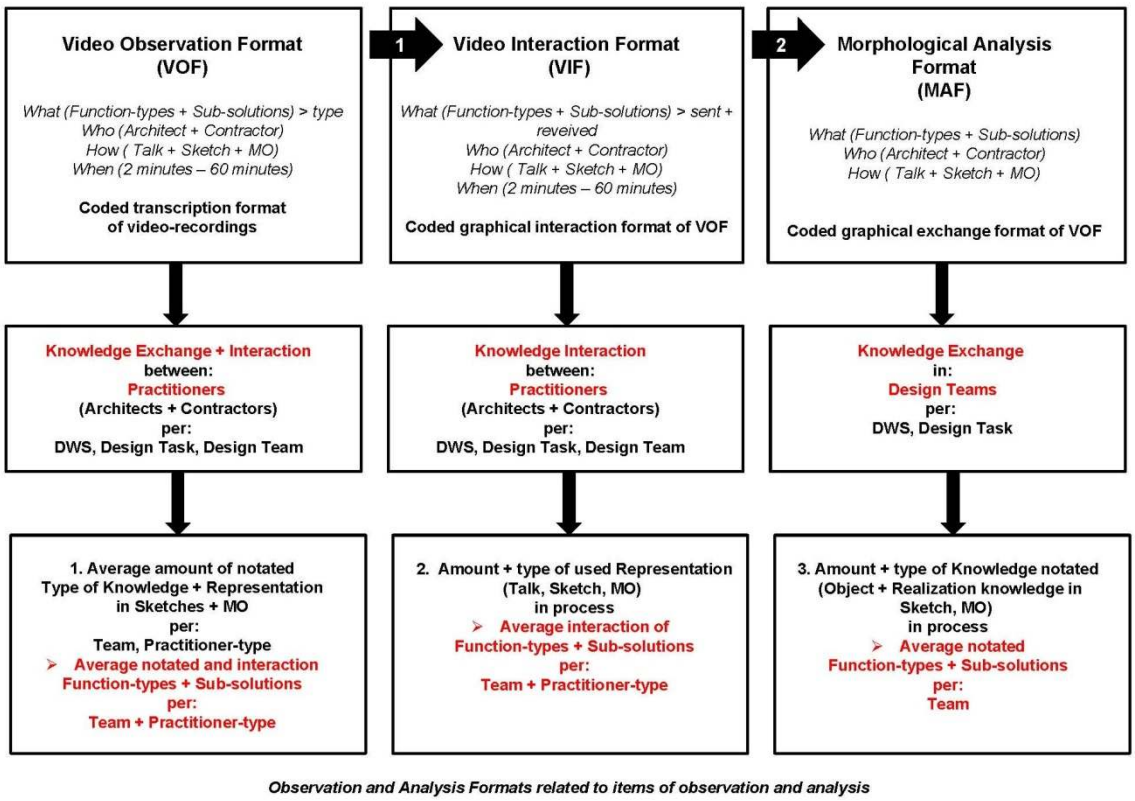


Figure 88 Overview of the used Observation and Analysis Formats, related to the items of observation and analysis.

DESIGN OUTPUT AND JUDGEMENT BY PEER REVIEWERS

The analysis of the results of the Workshop, the design output needs to be executed by using the Improved Research Analyses Protocol. This Improved Research Analyses Protocol uses the following data of each Design Team executed Design Task:
- Produced documents (sketches, notes, schema's, MO),
- Photographs of the produced documents (each 10 minutes)
- Video-recordings.

In this section the Analyses Protocol and the protocols to use the analyzing formats are described in order:
1. The Analyses Protocol;
2. Protocol 2.1 Collected Data from the Design Tasks;
3. Protocol 2.2 Collected Data from Evaluation practitioners from Interviews.

The execution of these protocols should be performed by the peer reviewers.

1. ANALYSIS PROTOCOL

First step: views all the produced documents and collects the notated function-types and sub-solutions with the reference list of function-types. This needs to be done to get the peer reviewers acquainted to the produced documents and complexity of notated function-types and sub-solutions. Therefore the data are not used in the analysis. The collected data are organized per team into the first draft of the MAF 1. For each team a separate MAF is used. Each format needs the notation of the following: Workshop-number, Design Task-number, and Design Team. Coding for Design Team: Design Task 1 (A*n*), Design Task 2 (B*n*), Design Task 3 (C*n*). Photographs are used to frame the time.

Second step: is to confirm the found function-types and related sub-solutions from step 1. This needs to be done by the use of the VOF for each video-taped team within a specific Design Task Setting. In this format the *what, how, when* and *who* of the specific communicated function-types are determined. This information needs also to be used to compare the influence of the use of the Morphological Overview (MO) for structuring and exchange of knowledge between the practitioners. All video-taped teams within one Design Task Setting need to be transcribed into the VOF with a specific coding for Workshop, task and team. In the format a specific coding needs to be used for type of functions and sub-solutions related to the reference function-type list (25 function-types, Figure 15, page 71) for object-related and realization-related function-types.

Third step: Derived from the VOF, the VIF needs to be made for each video-taped team within a specific Design Task Setting. This Interaction Format is a comprehensive graphical representation of communication types (*how)* related to the *what (function-types), when (time-frames of 2 minutes)* and *who (Architect or Contractor).*

Fourth step: The data from the VOF and VIF need to be organized in the MAF 2 for each monitored team. In this second draft of MAF 2 the found and confirmed sub-solution is added to the items from MAF 1. Items from MAF 1 are in blue, added items are in black. Additional in this step the overviews of the individual teams (MAF1, MAF2) in an overview for all teams within a specific Design Task Setting need to be combined in the MAF 3. The total amount of found realization knowledge notated during the design process needs to be counted and leads to the final overview notated in the MAF3.

Fifth and final step: In combination with the data of the VOF and the VIF per Design Task Setting and Design Team an overview needs to be organized for: type of practitioner (Architect, Contractor), type of function-types and sub-solutions notated (object- and realization-related) and communication-type (speech, sketch, MO).

In section 2 and 3, the protocols for the use of the analyzing formats are described.

2. PROTOCOL 2. 1: COLLECTED DATA FROM DESIGN TASKS

Protocol 2.1 concerns the data collection of the Design Tasks and the use of the VOF, the VIF and the MAF. First the types of data collection which are used during the Design Tasks are described. Second the transcription of these data using the VOF, VIF and MAF consecutively is described. The third part describes the judgment of the Design Output.

DATA TYPES COLLECTED

I All documents produced by all teams for each Design Task:

- A3-paper prepared, A3-paper MO-grid prepared, A3 sketch paper not prepared, notation paper A4/A3 not prepared
- All documents have the team code, given at start of the design task, notated on each documents
- Completeness of the produced documents and coding is checked after delivering the documents by trained assistants
- All collected documents are immediately stored in an A-3 portfolio, prepared, with notation of Workshop number / Design Task number / date

II Photographs of all Collaborative Design-teams for each Design Task

- Photographs of the produced documents; each 10 minutes, by trained assistants
- All photographs have the team code and number of sequence
- Completeness of the photographs and coding is checked after delivering the documents by trained assistants
- All photographs are immediately digitally stored on hard-disc-drive in digital map, prepared, with notation of Workshop number / Design Task number / date

III Video-recordings with sound, of 3 Collaborative Design-teams per Group, per Design Task

- Video recordings which envisions clearly the activities / discussion of the Collaborative Design Team during the design-task; by trained assistants
- Video tapes are prepared in advance; coding with notation Workshop number / Design Task / Collaborative Design Team number
- Lay-out, completeness of the videos and coding is checked after delivering the documents by trained assistants
- Video tapes are stored in separate Workshop-storage box; coding with Workshop number
- Video tapes are transformed to digital format after the Workshop; coding with notation Workshop number / Design Task / Collaborative Design Team number
- Digital format tapes are stored immediately on external hard-disc in digital map; coding with notation Workshop number / Design Task / Collaborative Design Team number

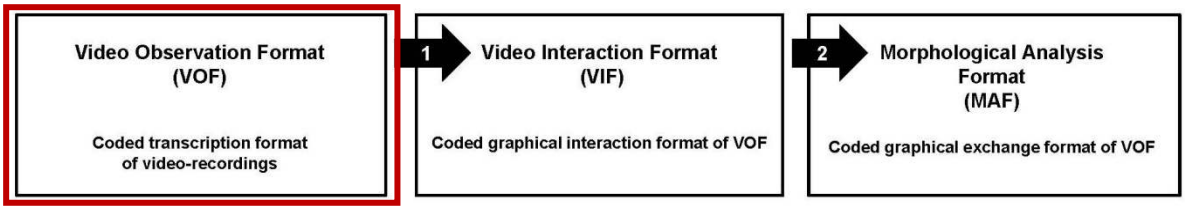
TRANSCRIPTION OF THE COLLECTED DATA

I Documents on paper
- Each separate documents produced by the different teams are analyzed
- Make copies of all separate documents
- Use listing / coding of realization-knowledge and object-knowledge as functions
- Notate on separate document – related to notated item – code of function type and/or number in sequence for notated sub-solution
- Example; EPDM-roof coating = water proof + sub-solution 1 = f1 ss1

II Photographs
- No transcription necessary

III Video-recordings
In order to transcribe the video-recordings clearly related to the overview and insight it show the transcription is in two steps:

III. A VIDEO OBSERVATION FORMAT (VOF)



The Video Observation Format (VOF) represents a coded transcription of the used communication-types (talk/speech, sketch, MO) and explicitly used and notated function-types and sub-solutions by the practitioners within a team, referring to: *what, who, when, how* of the collaborative design. The following steps should be taken in applying this VOF.

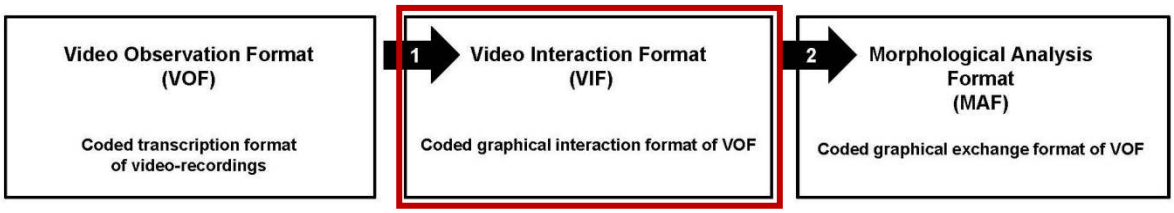
View the video-recording in total of the Design Team.
- This is necessary to get introduced in how the Design Team operates and to get an overview of used function-types and sub-solutions.
- Use the produced documents and the MAF 1 of the specific Design Team next to the video-recording to determine and orientate on the notated function-types and sub-solutions.

How to use the text transcription for communicated function-types and sub-solutions during design process:
- Use pre-defined text-transcription VOF-format 1 (Figure 89, in the green box; realization knowledge);
- Fill in the format: WS-number, Team-number and Design Task-number (left-top)
- View the video-tape in time-frames of 2 minutes; stop the tape; notate the information direct into the format; then continue with the next 2-minute time-frame
- Notate activity types related to the Design Task (function-types and sub-solutions) of Architect in the upper part of the VOF-format and those of the Contractor in the lower part of the VOF-format (2nd column of the format)
- Activity types are explicitly related to: The first use depicts the introduction of a task related function-type in general. Here, although the function-type is introduced, it does not necessarily become part of the design. The second use depicts the contribution of a function-type belonging to the reference list alongside the combination of other design contributions. The third use depicts contributions that were not present in the reference list, and as such are classified here as 'new' contributions (3rd column of the format: function-types and sub-solutions which are not direct related to the reference-list and Design Task).
- Make a choice which of the types of communication the practitioner is using: speech; notations on paper; notations in the MO related to: only function in general; the design task; new aspects of the design task (4rd column of the format);
- Notate the function-type and/or sub-solution which are used by the practitioner: use the listing / coding of realization-knowledge and object-knowledge as function-types as notated in the left-column of the VOF-format; these are the function-types of the reference-list
- Notate in front of the function-type / sub-solution what type of interaction the practitioner uses (use the symbols which are between brackets): activity type + sending (>) / receiving (<) / neutral (-)
- Use the following coding for the used function-types and sub-solutions within the team, related the numbering of the reference-list in the left column of the VOF
Example; EPDM-roof coating = water proof + sub-solution 1 = f1 ss1 = (f1 ss1)
- Highlight the function-types and sub-solutions with the coding system within the VOF

Functionalities / Solutions WS Team: Task:	Participant	Used	How		T 21 –22 minutes	T 23 -
f1= rain / water-proof f2 = temperature proof f3 = ventilation f4 = maintenance f5 = safety f6 = heating & cooling f7 = sustainable energy generation f8 =construct & build f9 = comfort & health f10 = accessibility f11 = operational f12 = light / sun-use & protection f13 = functions for building & roof f14 = orientation & sight f15 = construction f16 = costs & finance & benefit f17 = architecture f18 = sustainability f19 = building physics f20 = fire protection f21 = utilities f22 = shape f23 = material f24 = users f25 = flexibility > sent < receive - alone	ARCHITECT	only as function	speech / talking			
			on paper	sketch		
				MO		
		related to design > combination	speech / talking			
			on paper	sketch		
				MO		
		related to design > new	speech / talking			
			on paper	sketch		
				MO		
	CONTRACTOR	only as function	speech / talking			
			on paper	sketch		
				MO		
		related to design > combination	speech / talking			
			on paper	sketch		
				MO		
		related to design > new	speech / talking			
			on paper	sketch		
				MO		

Figure 89 Video Observation Format (fragment); Time-frame 20-30 minutes out of 60 minutes total.

III.B. VIDEO INTERACTION FORMAT (VIF):



The Video Interaction Format (VIF) represents types of interaction (send or received) and types of communication (talk/speech, sketch, MO) for used function-types and sub-solutions between the practitioners within one team for one design task, determined from the VOF transcription. The steps for using the VIF are described below.

How to use the VIF:
- Use pre-defined activity-transcription VIF (Figure 90, page 185):
- The lay-out of the VIF is the same as that of the VOF; only the time-frames of 2 minutes are organized on one A3-format for 60 minutes
- Time-frames of 2 minutes are related to; communication types of Architect and Contractor related to: speech; notations on paper; notations in the MO and related to: only function in general; the design task; new aspects of the design task;
- Notate coding: Workshop number / Design Task / Collaborative Design Team number (top left)
- Use the highlighted function-types and sub-solutions from the VOF of the corresponding Design Team
- Use time frames of 2 minutes each; notations within this 2-minute frame direct into format, than continue with next 2-minute time frame

The VIF contains the format for all found function-types and sub-solutions represented as color-coded arrows. The color-coding is used for the function-types (red or dark-blue) and sub-solutions (yellow or light-blue) related to interaction-type (send or received item). The color-coded arrows are placed in a specific box related to type of used in the design (only as function, related to the design – as combination, related to the design – as new solution) and type of representation in communication (talk/speech, sketch, MO). Horizontal axis is the time-schedule with the 2-minutes time-zones up to 60 minutes (*when)*. Vertical axis shows the knowledge representations. Each block-segment in colour represents one used functionality or sub-solution; the colour and direction represents the interaction-type. The direction of the arrow points out who of the participants is the sender or receiver. The position of the arrow in the VIF on a horizontal row is related to the communication-type which is used and when it is used. When a function-type or sub-solution is send- or received through one of the interaction-types this item is processed.

Coding system arrows:

Dark blue: sent function-type, processed

Light blue: sent sub-solution, processed

Red; sent function-type, not processed

Yellow: sent sub-solution, not processed

Although the focus is on notated object- and realization-related function-types and sub-solutions (dark blue and light blue arrows), the other notations are part of the total array of interaction and communication (talk, sketch, MO) between the Architect and Contractor related to the design task. So the total array of interaction and communication gives a view on the overall interaction between practitioners during the design process related to the design task.

Finally, an example of the used Video Interaction Format (Figure 90)

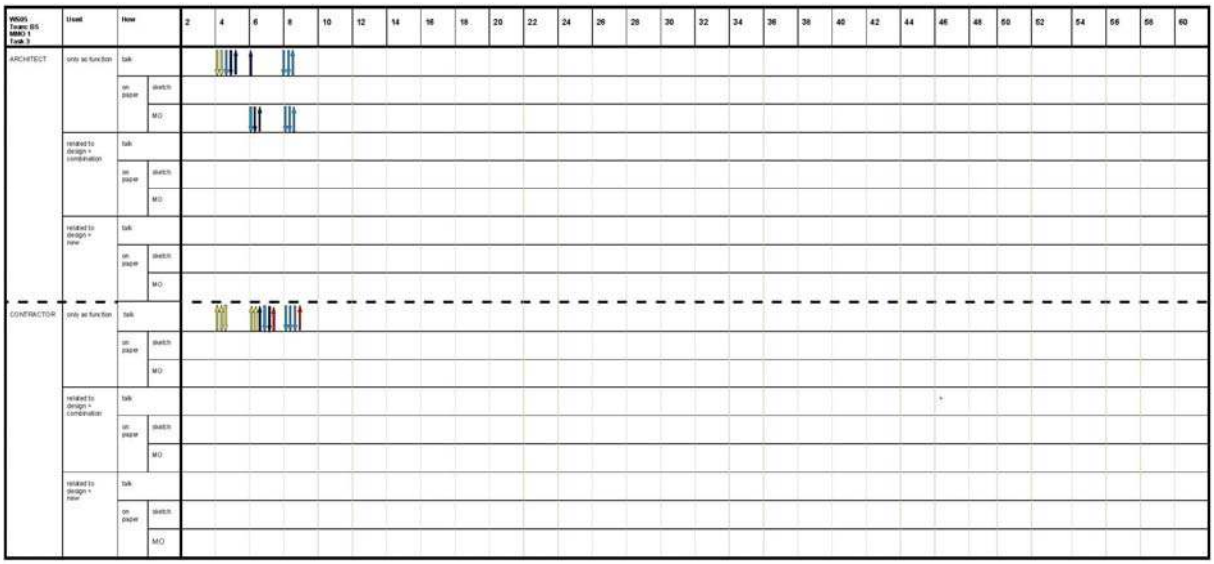


Figure 90 Video Interaction Format; showing a sequence of 60 minutes.

The next paragraph focuses on the different situations, interaction types, in which these coding needs to be used. The next graphical overviews (Figures 91.1, 91.2 and 91.3) show sequences of communication-types. Three different situations in communication-type needs to be discriminated, First only communication in speech (A. talk; Figure 91.1), second: communication in speech and notations in sketch and /or the Morphological Overview (B. talk + notated (sketch / MO; Figure 91.2) and third: communication only in notations (C. Notated (sketch / MO; Figure 91.3). For each of these types the different interaction types are described on the next pages.

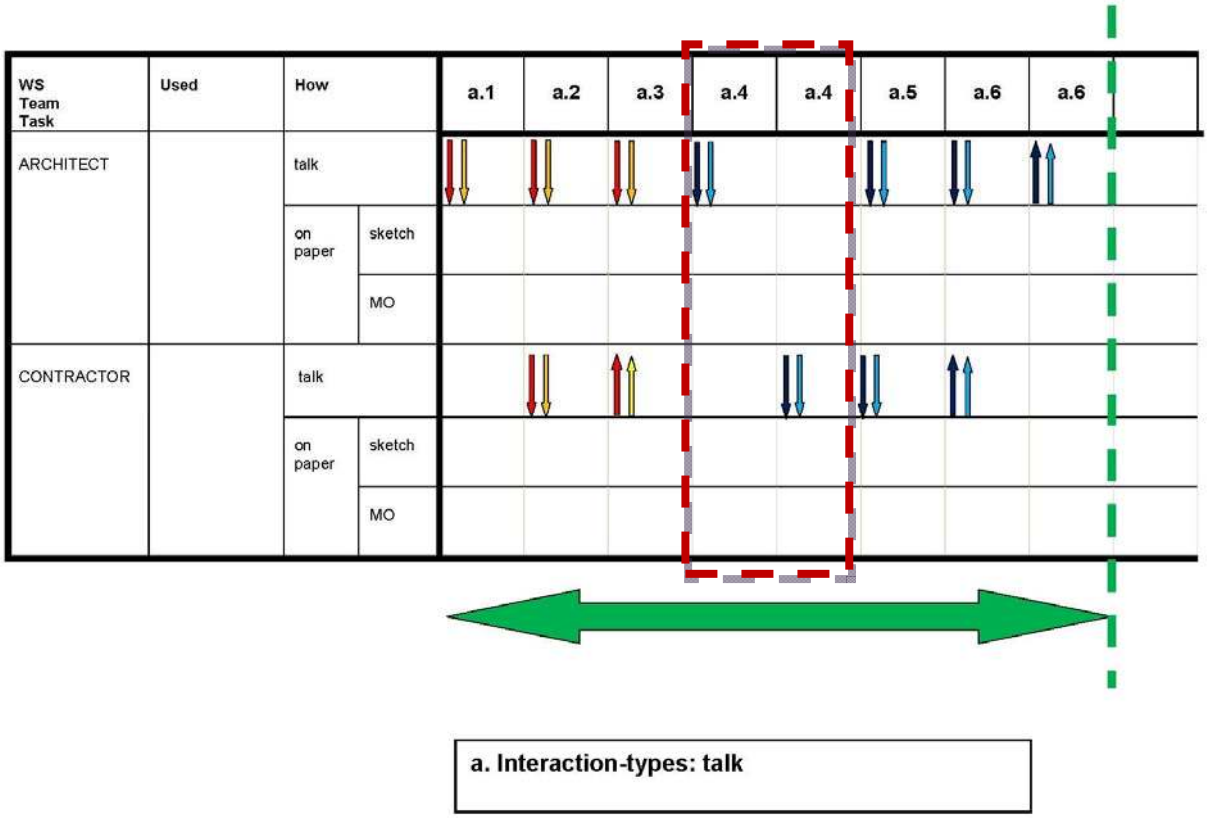


Figure 91.1 Communication: talk, interaction-types.

a. Communication: talk

In Figure 91.1 the different situations in interaction are organized in a vertical way. On the top horizontal row the interaction-type coding are organized with on the vertical connected column the example with the used notation coding in arrows or block. For example: example a.4 in the red-stripe box of Figure 91.1; send by the Architect to Contractor is a function-type (dark-blue arrow) and a sub-solutions (light-blue arrow). The following situations can be used (Figure 91.1):

a.1 a sent function-type or sub-solution which is not processed; not responded within the time-frame and not notated

a.2 a sent function-type or sub-solution which is not processed; responded by the other practitioner within the time-frame and not notated

a.3 a sent function-type or sub-solution which is not processed; not responded within the time-frame and /or not notated

a.4 a sent function-type or sub-solution which is processed; responded by the other practitioner within the time-frames; this could be a next time-frame of 2 minutes

a.5 a sent function-type or sub-solution which is processed; responded by the other practitioner within the time-frame with an additional aspect of the function-type (for example; send is ‘orientation’, respond is ‘sight’; both part of function-type ‘orientation and sight’) or related sub-solution

a.6 a sent function-type or sub-solution which is processed; responded by the other practitioner within the time-frame with another function-type or sub-solution which is respond to in next time-frames (a.5)

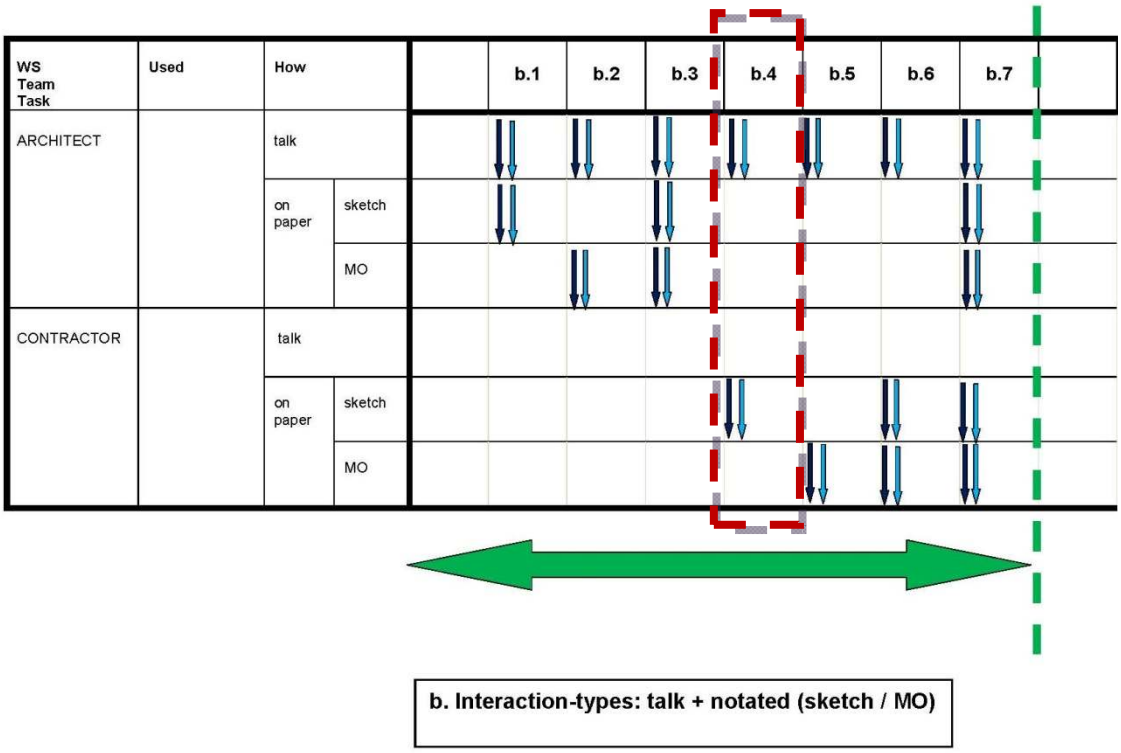


Figure 91.2 Communication: talk + notated (sketch / MO), interaction types.

b. Communication: talk + notated (sketch / MO)

In Figure 91.2 the different situations in interaction are organized in the same way as in Figure 91.1. The following situations can be used (Figure 91.2):

b.1 a sent function-type or sub-solution which is processed in a sketch by the same practitioner
b.2 a sent function-type or sub-solution which is processed in an MO by the same practitioner
b.3 a sent function-type or sub-solution which is processed in both a sketch and an MO by the same practitioner
b.4 a function-type or sub-solution which is sent by practitioner *a* and notated by practitioner *b* in a sketch
b.5 a sent function-type or sub-solution which is sent by practitioner *a* and notated by practitioner *b* in an MO
b.6 a sent function-type or sub-solution which is sent by practitioner *a* and notated by practitioner *b* in both a sketch and an MO
b.7 a sent function-type or sub-solution which is sent by practitioner *a* and notated by both practitioner *a* and practitioner *b* in both a sketch and an MO; or a variant to this

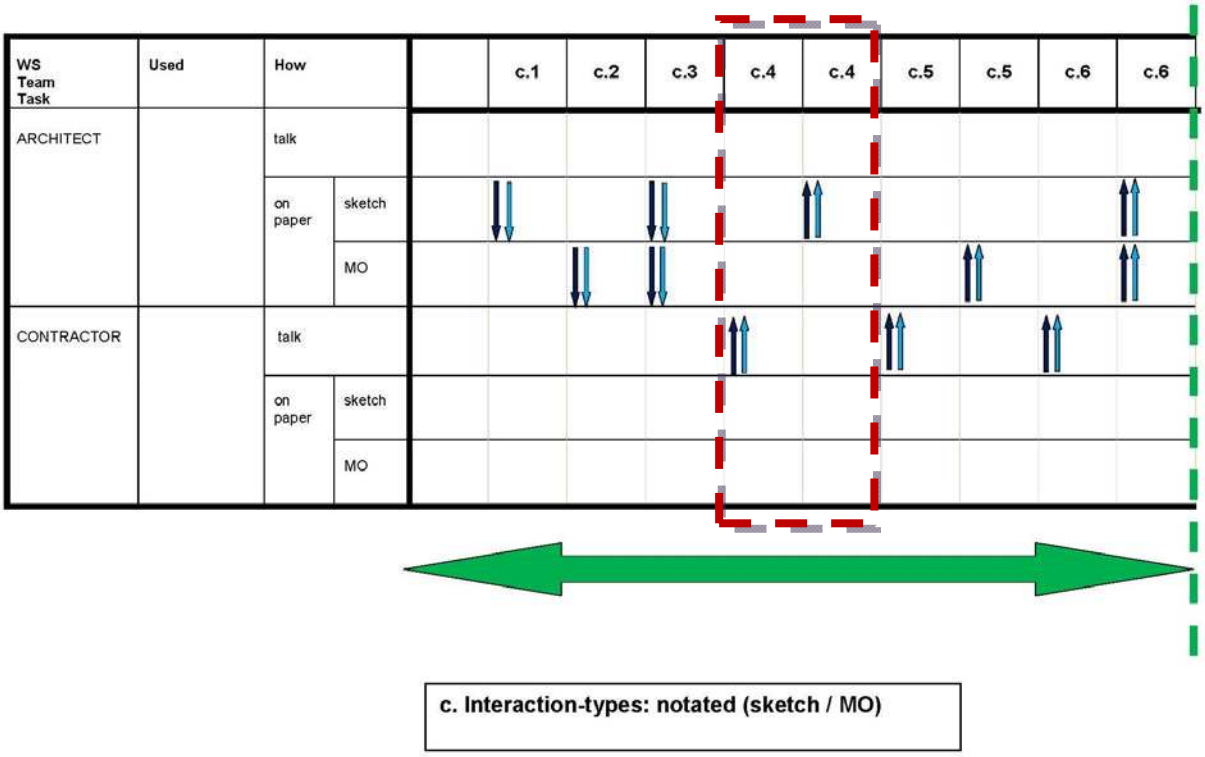


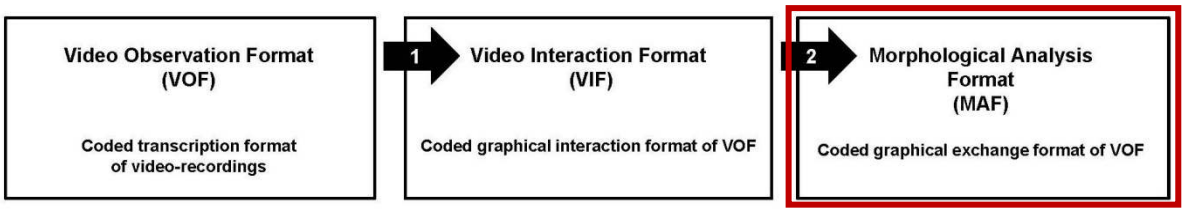
Figure 91.3 Communication: notated (sketch / MO), interaction types.

c. Communication: notated (sketch / MO)

In Figure 91.3 the different situations in interaction are organized in the same way as in Figure 91.1. The following situations can be used (Figure 91.3):

c.1 a function-type or sub-solution which is processed in a sketch by the same practitioner
c.2 a function-type or sub-solution which is processed in an MO by the same practitioner
c.3 a function-type or sub-solution which is processed in both a sketch and an MO by the same practitioner
c.4 a function-type or sub-solution which is sent by practitioner *b* in another time-frame next to this time-frame and notated by practitioner *a* in a sketch
c.5 a sent function-type or sub-solution which is sent by practitioner *b* in another time-frame next to this time-frame and notated by practitioner *a* in an MO
c.6 a sent function-type or sub-solution which is sent by practitioner *b* in another time-frame next to this time-frame and notated by practitioner *a* in both a sketch and an MO

III.C MORPHOLOGICAL ANALYSIS OVERVIEW (MAF):



The Morphological Analysis Overview (MAF) represents function-types and sub-solutions notated within each team for one design task, determined from the Video Observation Format transcription and with the following application steps.

How to use the MAF:
- Use pre-defined MAF (Figure 92):
- The lay-out of the MAF is organized in a vertical column with the function-type reference-list; this reference-list consists of 11 realization-related and 14 object-related function-types.
- For each function-type of the reference list the related sub-solutions which are notated by the design teams for one design-task, are organized
- Notate coding: Workshop number / Design Task / Collaborative Design Team number (top left)
- Notate coding for sub-solutions: sub-solution, and in brackets the Design-Team code (*An-Cn)* + if notated also in MO add coding MO (*An-MO)*

WS: TEAMS: TASK:								TOTAL SUB-SOLUTIONS
1. Rain / water proof								
2. Temperature proof								
3. Ventilation								
4. Maintenance								
5. Safety								
6. Heating & Cooling								
7. Sustainable energy generation								
8. Construct & Build								
9. Comfort & Health								
10. Accessibility								
11. Operational								
SUB-TOTAL REALIZATION F: Σ F 1-11 (%) REALIZATION F IN MO: Σ F 1-11 - MO								SUB-TOTAL REALIZATION SS: Σ SS 1-11 (%) REALIZATION SS IN MO: Σ SS 1-11 - MO
12.Light / Sun-use & Protection								
13.Functions for building & roof								
14. Orientation & Sight								
15. Construction								
16. Costs & Finance & Benefit								
17. Architecture								
18. Sustainability								
19. Building Physics								
20. Fire protection								
21. Utilities								
22. Shape								
23. Material								
24. Users								
25. Flexibility								
SUB-TOTAL OBJECT F: Σ F 12-25 (%) OBJECT F IN MO: Σ F 12-25 - MO								SUB-TOTAL OBJECT SS: Σ SS 12-25 (%) OBJECT SS IN MO: Σ SS 12-25 - MO
TOTAL F: Σ F 1-25 TOTAL F IN MO: Σ F 1-25 - MO (%)								TOTAL SS: Σ SS 1-25 TOTAL SS IN MO: Σ SS 1-25 – MO (%)

Figure 92 Morphological Analysis Format. In the Green Box: realization-knowledge function-types.

DESIGN OUTPUT AND JUDGEMENT

General remark: an analysis of the total workshop activities is only possible when all produced documents, digital photographs, video-recordings of the activities and output of each team are available. The workshop management should be careful not to lose data due to ill functioning equipment, like camera's and camcorders. How the peer reviewers should handle this in a practical way is described in the Workshop Script of Protocol Appendix 2 (page 197 – 198).

The data of the Video Observation Format and the Video Interaction Format are needed to determine the next aspects:

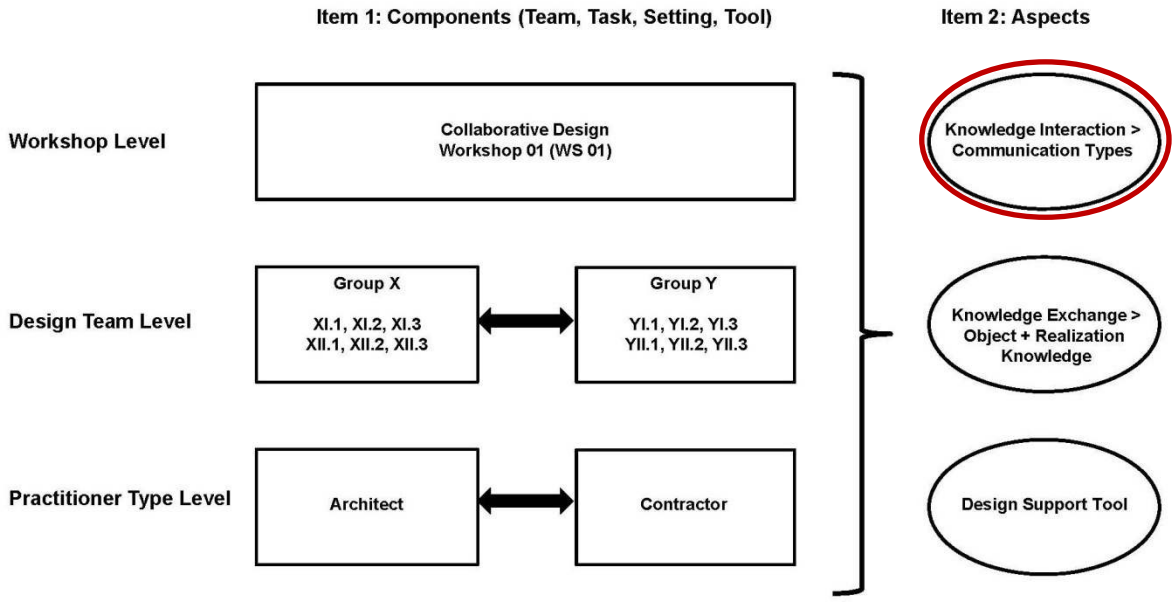
A. The variety of used communication-types (Speech/talk, Sketch and MO) by the different practitioners as interaction between Architect and Contractor; the flow of interaction.

B. The individual contributions, explicitly notated object- and realization knowledge (Sketch, MO) in a specific team; knowledge exchange.

C. The individual contributions, object- and realization knowledge explicitly notated in the Design Support Tool in a specific team; use of the MO.

For each aspect the following items are described: Steps, Calculation, and Outcomes for comparison, Judgment on outcomes.

A. The variety of used communication-types (Speech/talk, Sketch, MO) by the different practitioners as interaction between Architect and Contractor; interaction flow.)



Levels and items of comparison in observation and analysis

***A* STEPS**

- Use VIF for the specific Design Task related to the Morphological Overview (without MO and with MO) and Design Team.
- Construct an Interaction Overview in the way as Figure 93.
- Figure 93 shows an Interaction Overview for one team per Design Task Settings, derived from the amount of communication-types – with corresponding coding – in the VIF. The VIF in Figure 93 needs to be used to transcribe the amount of communication-types of the VIF into a table with numbers.
- Construct an Interaction Overview Total: Figure 94 (Interaction Overview Total). The table of Figure 94 is a comprehensive overview derived from the Interaction Overviews of the individual Design Teams as a total for all Design Teams within one Design Task Setting.
- Both tables use the lay-out and coding of the VIF for the left-side columns. On the horizontal axis the amount of the different communication-types have to be notated, as well as the total sub-amounts and total amounts in numbers and percentages.
- First the results of design tasks of the individual Design Teams need to be calculated, and then all Design Teams of a Design Task are added in this overview.
- Depended to the step of analysis the Interaction Overview Total will be modified.
- Make vertical 2 rows for Architect and Contractor and 2 main columns for function-types (F) and sub-solutions (SS).
- Divide each main column into 4 sub-columns for the communication-types and the total score; talk / speech, sketch, MO, total F / SS.
- Count and notate for each type of practitioner and per communication-type the amount of: dark blue and dark red (function-types), light blue and yellow (sub-solutions) arrows,
- For each communication type the sub-totals need to be organized in the columns for Sub-total Processed and Sub-total Not Processed. See columns with vertical black arrow in Figures 93 and 94.
- For each type of send-received type (arrow-types) the sub-totals need to be organized in the columns for Sub-total Processed and Sub-total Not Processed. See rows with horizontal grey arrow in Figures 93 and 94.

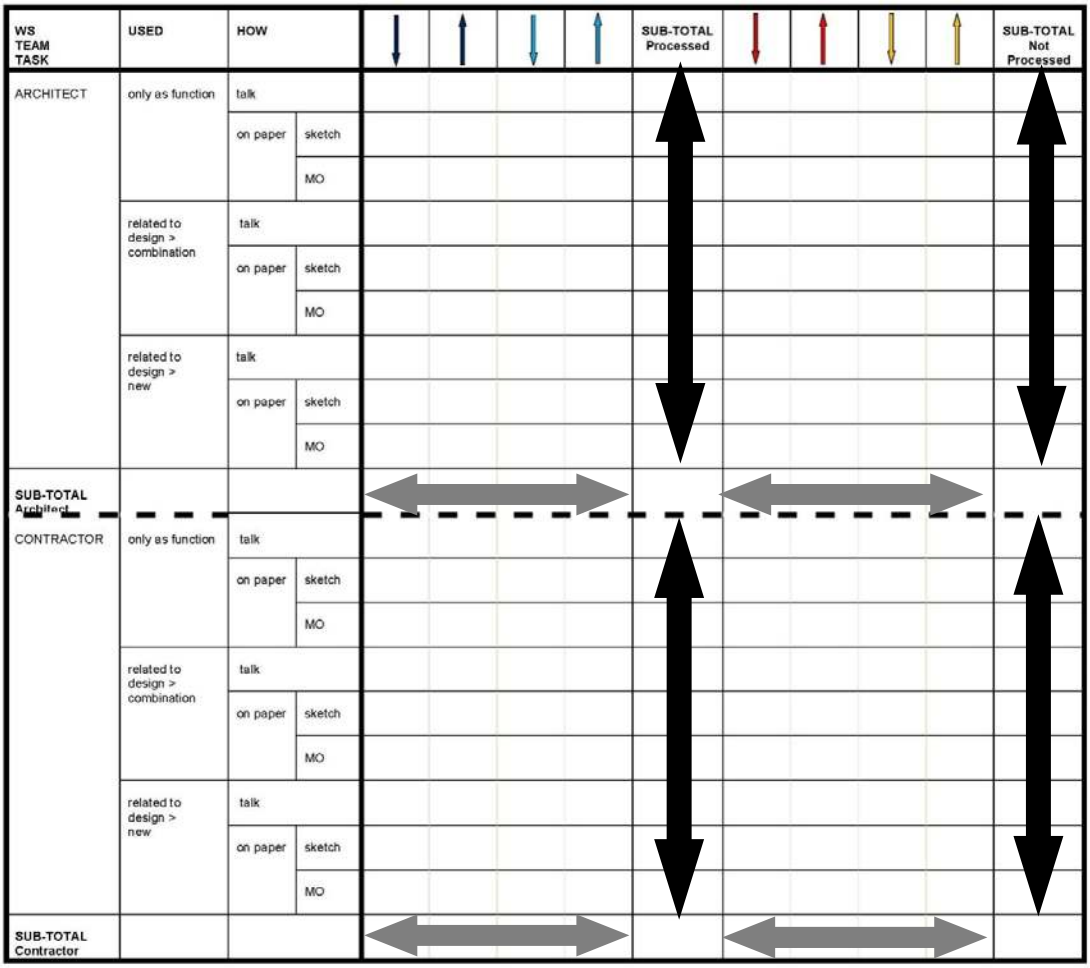


Figure 93 Interaction Overview Design Team: notation format for amount of interaction-types per communication-type.

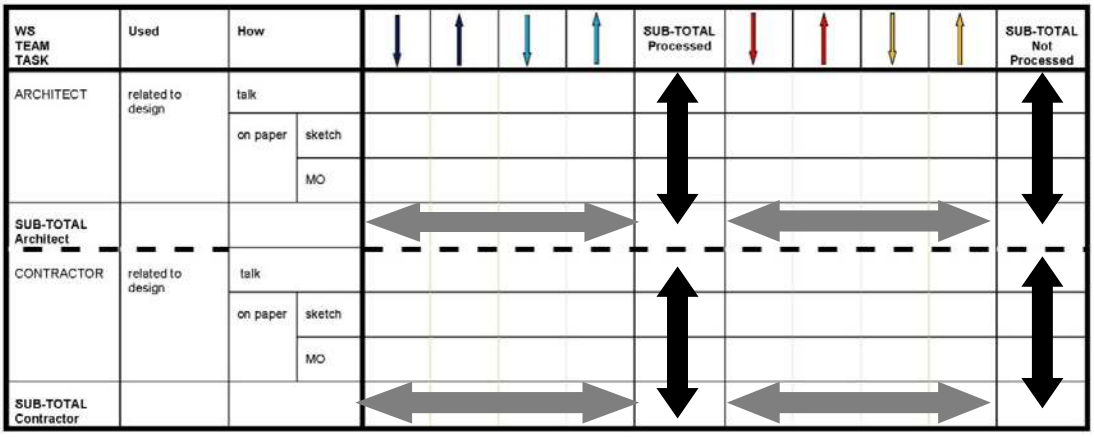


Figure 94 Interaction Overview Design Task Setting: notation format for total amount of interaction-types per communication-type.

A CALCULATION

Comparisons have to be made on Design Task-level and on Workshop-level. At design task level, two comparisons have to be made: 1a) Design Task-level and 1b) Design Task-level Total.

1a) Design Task-level *(Interaction Overview), Figure 93*:
Calculated is the interaction as the contribution of each practitioner type (Pract. type *p;* Architect or Contractor). The contribution is characterized as communication type (Com. type *c;* talk, sketch, MO). Contributions are as function-type (dark blue and dark red arrows) or as sub-solution (light-blue arrow or yellow arrows). For each team of a specific Design Task this calculation is executed and finally summarized per Design Task and Workshop. For each communication type (Com. type *c*) and practitioner type (Pract. type *p*), the following formula have to be used:

Interaction Function-types, Pract. type *p,* Com. type *c* = Σ arrows dark blue (Com. Type c)

Interaction Function-types, Pract. type *p,* Com. type *c* = Σ arrows dark red (Com. Type c)

Interaction Sub-solutions, Pract. type *p,* Com. type *c* = Σ arrows light blue (Com. Type c)

Interaction Sub-solutions, Pract. type *p,* Com. type *c* = Σ arrows yellow (Com. Type c)

1b) Design Task-level Total *(Interaction Overview Total), Figure 94:*
First is calculated is the total amount of interaction within one Design Task Setting for all Design Teams as the contribution of each practitioner type (Pract. type *p;* Architect or Contractor). The contribution and notations are the same as for the Interaction Overview. The following formulas for each communication type have to be used:

Interaction Function-types, Pract. type *p,* Com. type *c* = Σ arrows dark blue (Com. Type c), all Design Teams, Design Task *n*

Interaction Function-types, Pract. type *p,* Com. type *c* = Σ arrows dark red (Com. Type c), all Design Teams, Design Task *n*

Interaction Sub-solutions, Pract. type *p,* Com. type *c* = Σ arrows light blue (Com. Type c), all Design Teams, Design Task *n*

Interaction Sub-solutions, Pract. type *p,* Com. type *c* = Σ arrows yellow (Com. Type c), all Design Teams, Design Task *n*

Secondly is calculated the average amount of interaction within one Design Task Setting for all Design Teams as the contribution of each practitioner type (Pract. type *p;* Architect or Contractor). The contribution and notations are the same as for the Interaction Overview. The following formulas for each communication type have to be used:

Interaction Function-types, Pract. type *p,* Com. type *c* = Σ arrows dark blue (Com. Type c), all Design Teams, Design Task *n* / Σ Design Teams Monitored

Interaction Function-types, Pract. type *p,* Com. type *c* = Σ arrows dark red (Com. Type c), all Design Teams, Design Task *n* / Σ Design Teams Monitored

Interaction Sub-solutions, Pract. type *p,* Com. type *c* = Σ arrows light blue (Com. Type c), all Design Teams, Design Task *n* / Σ Design Teams Monitored

Interaction Sub-solutions, Pract. type *p,* Com. type *c* = Σ arrows yellow (Com. Type c), all Design Teams, Design Task *n* / Σ Design Teams Monitored

2) Workshop-level:
All workshop data need to be compared. So, by executing for instance three Workshops (or more) the results of the 3rd need to be used as a correction of the comparison of the other two. When there are only two workshops, the total number of scores per Design Task-level need to be divided by 2. The outcome is 'WS Total', which is an average result.

The outcomes of the above analyses need to be used for the next two comparisons. These comparisons concern the communication types: 1) *Within* a Design Task and 2) *Between* Design Tasks.

1) *Within* a Design Task
For comparison of communication-types *within* a Design Task the scores in total need to be set at 100%. This needs to be done separately for function-types and sub-solutions.
2) *Between* specific Design Tasks
To compare the communication-types *between* specific Design Tasks, the average scores per communication-type are joined up for all Design Tasks per practitioner-type. The scores for both practitioner-types need to be set at 100%. Finally for each practitioner-type the average percentage of used communication-type need to be calculated.

When the above calculations are made, three comparisons need to be made:
1. Processed and Not Processed items: the percentage of all used interaction-types (dark blue, dark red, light blue, yellow arrows) within a Design Task Setting need to be set at 100%. See Figure 95.
2. Communication types: the percentage of all explicit processed (dark blue arrow, light blue arrow) for communication-types (talk, sketch, MO). All processed types within one Design Task Setting need to be set at 100%. See Figure 96 and Figure 97.
3. Interaction types: the percentage of explicit sent and received function-types (F: dark blue arrow) and sub-solutions (SS: light blue arrow). All sent and received interaction types within one Design Task Setting need to be set at 100%. See Figures 98.1 and 98.2 (page 195). The grey boxes in the overviews for X1 and Y1 are used for the design task in which the MO is not used.

PARTICPANT TYPE	COMMUNICATION-TYPE	TASK 2 XI XI.1, XI.2, XI.3, XI.*n*		TASK 2 YI YI.1, YI.2, YI.3, YI.*n*		TASK 3 XII XII.1, XII.2, XII.3, XII.*n*		TASK 3 YII YII.1, YII.2, YII.3, YII.*n*	
		PROCESSED	NOT PROCESSED	PROCESSED	NOT PROCESSED	PROCESSED	NOT PROCESSED	PROCESSED	NOT PROCESSED
ARCHITECT	TALK	%	%	%	%	%	%	%	%
	SKETCH	%		%		%			
	MO	0%		0%		%			
	TOTAL A	%	%	%	%	%	%	%	%
CONTRACTOR	TALK	%	%	%	%	%	%	%	%
	SKETCH	%		%		%			
	MO	0%		0%		%			
	TOTAL C	%	%	%	%	%	%	%	%
GENERAL PROCESSED / NOT		%	%	%	%	%	%	%	%

Figure 95 Interaction Overview Processed and Not Processed.

WS TEAM	HOW	WS TOTAL TASK 2 XI / TEAM XI.1, XI.2, XI.3, XI.*n*		WS TOTAL TASK 2 YI / TEAM YI.1, YI.2, YI.3, YI.*n*		WS TOTAL TASK 3 XII / TEAM XII.1, XII.2, XII.3, XII.*n*		WS TOTAL TASK 3 YII / TEAM YII.1, YII.2, YII.3, YII.*n*	
		AVERAGE F	AVERAGE SS	AVERAGE F	AVERAGE SS	AVERAGE F	AVERAGE SS	AVERAGE F	AVERAGE SS
ARCHITECT	TALK	%	%	%	%	%	%	%	%
	SKETCH	%	%	%	%	%	%	%	%
	MO					%	%	%	%
AVERAGE ARCHITECT		**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**
CONTRACTOR	TALK	%	%	%	%	%	%	%	%
	SKETCH	%	%	%	%	%	%	%	%
	MO					%	%	%	%
AVERAGE CONTRACTOR		**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**

Figure 96 Interaction Overview Communication-types per Design Task Setting.

WS TEAM	HOW	WS TOTAL TASK 2 XI, YI / TEAM		WS TOTAL TASK 3 XII, YII / TEAM	
		AVERAGE F	AVERAGE SS	AVERAGE F	AVERAGE SS
ARCHITECT	TALK	%	%	%	%
	SKETCH	%	%	%	%
	MO			%	%
AVERAGE ARCHITECT		**%**	**%**	**%**	**%**
CONTRACTOR	TALK	%	%	%	%
	SKETCH	%	%		%
	MO			%	%
AVERAGE CONTRACTOR		**%**	**%**	**%**	**%**

Figure 97 Interaction Overview Communication-types average, per Design Task Setting.

The comparisons of interaction concerning function types and sub-solutions need to be made as follows: To indicate the similarity of interaction between contractor and architect the diagonal arrows are used. To indicate effectiveness of interaction the vertical arrows are used. In Figure 98.1 and 98.2 these arrows are shown.

DWS TOTAL	TASK 2 NMO / XI FUNCTION-TYPES			TASK 2 MO1 / YI FUNCTION-TYPES			TASK 3 MO1 / XII FUNCTION-TYPES			TASK 3 MO2 / YII FUNCTION-TYPES		
	↓	↑	TOTAL F	↓	↑	TOTAL F	↓	↑	TOTAL F	↓	↑	TOTAL F
ARCHITECT	%	%	%	%	%	%	%	%	%	%	%	%
CONTRACTOR	%	%	%	%	%	%	%	%	%	%	%	%
COMPARABLE	0,C	0,C		0,C	0,C		0,C	0,C		0,C	0,C	
EFFECTIVENESS	0,E	0,E		0,E	0,E		0,E	0,E		0,E	0,E	

Figure 98.1 Interaction Overview Interaction-type 1, function types.

DWS TOTAL	TASK 2 NMO / XI SUB-SOLUTIONS			TASK 2 MO1 / YI SUB-SOLUTIONS			TASK 3 MO1 / XII SUB-SOLUTIONS			TASK 3 MO2 / YII SUB-SOLUTIONS		
	↓	↑	TOTAL SS	↓	↑	TOTAL SS	↓	↑	TOTAL SS	↓	↑	TOTAL SS
ARCHITECT	%	%	%	%	%	%	%	%	%	%	%	%
CONTRACTOR	%	%	%	%	%	%	%	%	%	%	%	%
COMPARABLE	0,C	0,C		0,C	0,C		0,C	0,C		0,C	0,C	
EFFECTIVENESS	0,E	0,E		0,E	0,E		0,E	0,E		0,E	0,E	

Figure 98.2 Interaction Overview Interaction-type 2, sub-solutions.

The percentages in the setting the diagonal arrow point at, indicates the sending and receiving of function-types and sub-solutions by Contractor and Architect. In a positive situation the percentages on the diagonal axis are similar; the interaction between Contractor and Architect is at the same level. Both are sending and receiving in an equal manner! The extent to which this interaction is similar is presented by the factors in the row in the table (Figures 98.1 and 98.2) named: ‘comparable’. The most positive situation is expressed when the factor in the row ‘comparable’ is 1,0.

The vertical arrow in Figures 98.1 and 98.2 expresses the effectiveness of sent and received function-types and sub-solutions. Here the most positive situation is when all *sent* items are *received* by the other practitioner. This implies an equal percentage for both. So: the *sent* percentage of the Architect compared to the *received* percentage of the Contractor in the left column, or the other way around in the right column. The effectiveness of the interaction is highest if the factor in the row ‘effectiveness’ of Figures 98.1 and 98.2 is 1,0.

A JUDGEMENT

The judgment on outcomes needs to be done on the next three aspects:
1. Interaction-type Processed and Not Processed (Figure 95, page 194):
On the level of interaction in the Design Teams the first analysis needs to determine whether there is interaction or not. This needs to be done by the overview where all different types of interaction within the Design Teams are viewed; see Figure 95. This overview is divided in Processed and Not Processed items for the communication-types: Talk, Sketch and MO. First judgment needs to be done on the aspect if there are used communication-types at all, processed are not. If so, then the comparison needs to be made between Processed and Not Processed items. Aim of the CD Workshop is to stimulate interaction, so the judgment needs to be on the increase of Processed interaction during the Workshop as a comparison between Design Task *n* and Design Task *n+1*. The following criteria for judgment should be used:
Negative: no or decrease of Processed interaction during the Workshop between Architect and Contractor, in comparison of Design Task *n* and Design Task *n+1*.
Positive: increase of Processed interaction during the Workshop between Architect and Contractor, in comparison of Design Task *n* and Design Task *n+1*
More positive is: increase of *notated* Processed interaction (Sketch, MO) during the Workshop between Architect and Contractor in comparison of Design Task *n* and Design Task *n+1*.
Most positive is: increase of *notated* Processed interaction (Sketch, MO) during the Workshop between Architect and Contractor, with an equal contribution of the Contractor compared to the Architect, in comparison of Design Task *n* and Design Task *n+1*.
2. When Processed: Communication-types (Figure 96 + Figure 97, page 195):
Important is if the Architect and especially the Contractor are able to give input (function-types and sub-solutions) to the discussion about the Design Task through the use of communication-types: Talk, Sketch and MO. Because the practitioner-types of Architect and Contractor have different educational background and equality-judgment will not give a good insight. This because the Architect is expected to have more skills related to notate explicitly function-types and sub-solutions compared to the Contractor (dark blue and light blue arrows). First should be determined if the Contractor uses the different communication types at all. Secondly should be determined if for a specific communication-type there is an increase or decrease of used communication-type for the different Design Tasks in the Workshop. The following criteria for judgment should be used:
Negative: no function-types (F) or sub-solutions (SS) are communicated and notated by the Contractor and Architect.
Positive: amount of function-types (F) and sub-solutions (SS) are communicated and notated by the Contractor and Architect.
More positive: amount of function-types (F) and sub-solutions (SS) are communicated and notated by the Contractor in equal contribution compared with the Architect.
Most positive: an increase of the amount of notated function-types (F) and sub-solutions (SS) by the Contractor in equal contribution compared with the Architect, in comparison of Design Task *n* and Design Task *n+1*.
For this judgment the results of average notated function-types (F) and sub-solutions (SS) – in percentages of total notated (%) – of the table in Figure 95 (page 194) are used and compared (black arrow). The judgment is on team-level between all teams of the Design Task Setting in one workshop (Figure 96, page 195). The second judgment is on team-level between the average of Design Task Setting task 2 and task 3 (Figure 97).
3. When Processed: Interaction-types (Figure 98.1, Figure 98.2, page 195):
Additionally to the use of communication-types the interaction needs to be judged on the use of interaction-types. This implies that both Architect and Contractor send and receive items (function-types and sub-solutions) about the Design Task. There are two way of judgment. First; on the similarity of used interaction-types. Second; on the effectiveness of used interaction-types. If there are only send items of one type of participant the interaction is not in balance only one participant is

sending and the other not. There is not an optimal effect of the interaction if the send items are only processed by the sender and not by the receiver.

3.1 Comparable

In the coding of the VIF this implies that there should be at least send and received items for both Architect and Contractor. As stated, it can be expected that the Architect will notate most of the sent and received items. What is of importance for the judgment is if, first; the Contractor will send and receive items, second; if there is a comparable situation in sent and received items compared with the Architect, third; if there is an increase of contribution in sent and received items in this comparison. Figure 98.1 (page 195): diagonal related % in matrix, black diagonal arrow (division of the two percentages). The division of these two percentages is the comparable-factor; 0,C. The following criteria for judgment should be used:

Negative: no function-types and sub-solutions are sent and received notated by the Architect and the Contractor (comparable-factor less than 0,50).

Neutral: no function-types and sub-solutions are sent and received by the Contractor, only by the Architect (comparable-factor is 0,50).

Positive: function-types and sub-solutions are sent and received by the Contractor and the Architect.

More positive: function-types and sub-solutions are send and received by Contractor in an equal manner compared with the Architect (comparable-factor more than 0,50).

Most positive: function-types and sub-solutions are sent and received by Contractor in an equal manner compared with the Architect and in an increase of the amount in comparison of Design Task *n* and Design Task *n+1* (comparable factor is 1,0).

For this judgment the results of average sent and received function-types (F) (Figure 98.1) and sub-solutions (SS) (Figure 98.2, page 195) – in percentages of total notated (%) – need to be compared. This implies a comparison (division of the two percentages) of input and balance in a diagonal way in the table (black diagonal arrow in Figure 98.1 and Figure 98.2); a comparable situation of sent items of Architect and received items by Contractor and vice versa.

3.2 Effectiveness

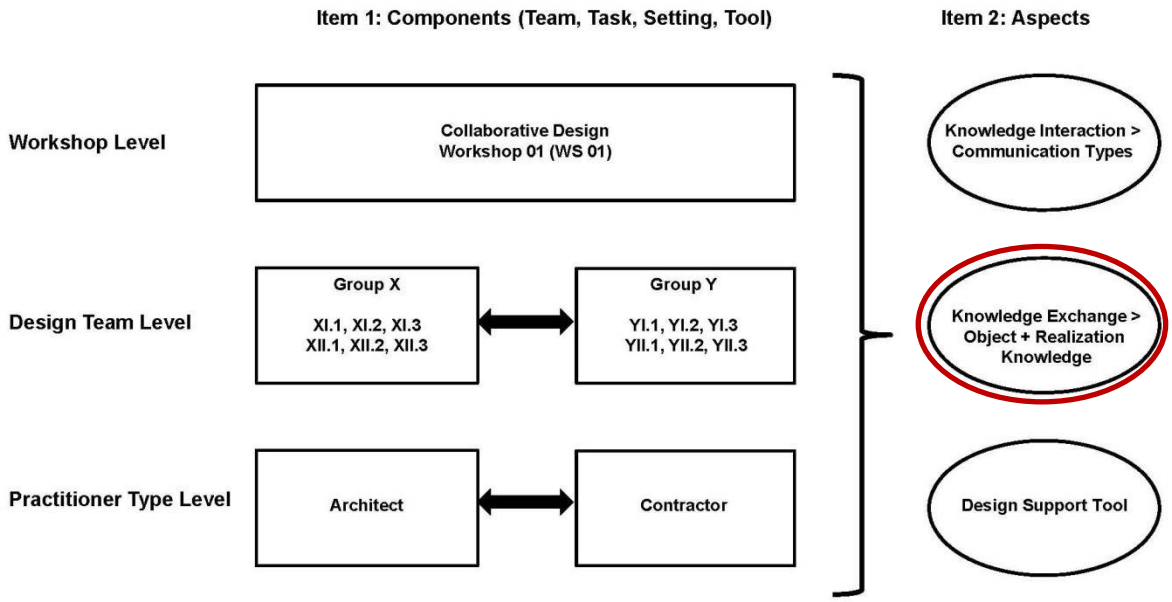
In the coding of the VIF this implies that sent items for one participant should be as much as possible been received by the other participant (speech, notations and MO). The most optimum is that all sent items are received by the other participant. This implies a more or less equal percentage in a column for Architect and Contractor in Figure 98.2 (vertical black arrow). The division of these two percentages is the effectiveness-factor; 0,E. The following criteria for judgment should be used:

Positive: an equal percentage of function-types and sub-solutions are sent and received by Contractor and Architect (effectiveness-factor is 1,0).

Negative: an on-equal percentage of function-types and sub-solutions are sent and received by Contractor and Architect (effectiveness-factor less than 0,50).

For this judgment the results of average sent and received function-types (F) (Figure 98.1) and sub-solutions (SS) (Figure 98.2) – in percentages of total notated (%) and compared. This implies a comparison of effectiveness in a vertical way (division of the two percentages) in the table (black vertical arrow in Figure 98.1 and Figure 98.2).

B. The individual contributions, explicitly notated object- and realization knowledge (Sketch, MO) in a specific team; knowledge exchange.



Levels and items of comparison in observation and analysis

***B* STEPS**

- Use the VOF and VIF for the specific Design Task (without MO and with MO) and Design Team.
- Construct a Contribution overview: Contribution Overview (see Figure 99) and corresponding graph (Figure 100). These Figures represent the average notated sub-solutions of the individual practitioner-types during the process for one specific Design Task Setting.
- Make vertical 2 rows for Architect (practitioner-type A) and Contractor (practitioner-type C) and 25 main columns for the function-types (f*n*) from the reference list (object- and realization-knowledge).
- Divide each main column into 2 sub-columns for: *sent* and *documented.*
- Only communication is taken into account which leads to explicitly notated function-types (dark-blue arrows) and sub-solutions (light-blue arrows).
- Use the results of the analysis of the use of the VIF.
- Use the notations in the VOF related to sent and documented function-types and related sub-solutions for each practitioner-type.
- Count for each type of practitioner and per function-type the amount of: dark blue (function-types) and light blue (sub-solutions) arrows related to *sent* and *documented.*

- Additionally organize the results of the VOF into a MAF2 for each Design Team: this is the summation of both practitioner-types in one Design Team related to documented function-types and related sub-solutions for a specific Design Task (Design Task *n*). The total overview for all Design Teams in one Design Task is documented in a MAF3. In this overview sub-totals for each knowledge-type are added and the total for all documented function-types (F) and sub-solutions (SS) and only documented in the MO. An example of such a MAF3 is presented in Figure 101 (page 201) .
- From these MAF3 a comprehensive overview is derived with the total-results per Design Task Setting and per DWS: the Team Contributions Overview (see Figure 102, page 201).
- Function-types (F) are notated as amount of notated related to the possible amount of function-type in the reference list per knowledge type: object- (14 function-types) or realization-related (11 function-

types). The notation is: *n* out of 14 (object-related), *n* out of 11 (realization-related). In brackets the % is notated.
- Sub-solutions (SS) are notated as the average amount of notated by the Design Team for a specific Design Task as part of all notated sub-solutions for this Design Task (Design Task *n*). In brackets the % is notated.
- When all teams of one Design Task are organized combine these results into a MAF3 for all Design Teams for one Design Task (see format Figure 101 page 201).
- Notate between brackets for each notated function-type and / or sub-solution: code of Design Team (A*n*), code of notated in the Morphological Overview (MO).
- The sub-totals and totals in notated function-types (F) and sub-solutions (SS) from all MAF3 from one DWS should be organized in one overview: The Team Contribution Overview (see format Figure 102, page 201).

WS*n* Task *k*	**Practitioner-type A**	**Practitioner-type C**
1. Rain / waterproof		
2. Temperature proof		
3. Ventilation		
4. Maintenance		
5. Safety		
6. Heating & Cooling		
7. Sustainable energy generation		
8. Construct & Build		
9. Comfort & Health		
10. Accessibility		
11. Operational		
12. Light / sun-use & Protection		
13. Functions building & roof		
14. Orientation & Sight		
15. Construction		
16. Costs & Finance & Benefit		
17. Architecture		
18. Sustainability		
19. Building physics		
20. Fire protection		
21. Utilities		
22. Shape		
23. Material		
24. Users		
25. Flexibility		

WS*n* Task *k*	**Practitioner-type A**	**Practitioner-type C**
TOTAL Realization-related		
TOTAL Object-related		

Figure 99 Contribution Overview.

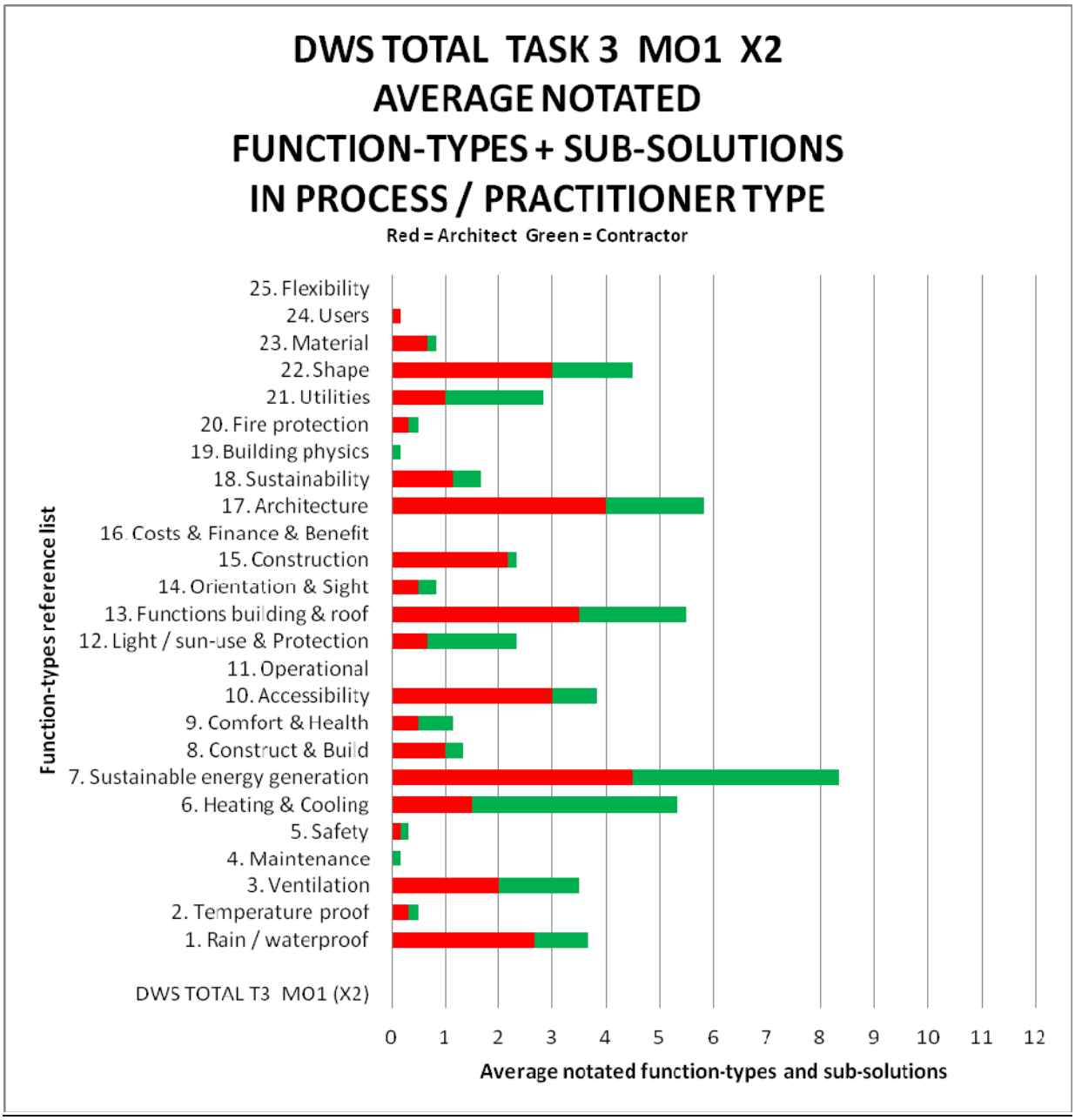


Figure 100 Contribution Overview: graphical format (example of DWS Total MO1 / Group X2).

DWS *n* Teams: C*n*- C*nn* Task: *p*								Total sub-solutions
1. Rain / water proof								
2. Temperature proof								
3. Ventilation								
4. Maintenance								
5. Safety								
6. Heating & Cooling								
7. Sustainable energy generation								
8. Construct & Build								
9. Comfort & Health								
10. Accessibility								
11. Operational								
SUB-TOTAL REALIZATION F: Σ F 1-11 (%) REALIZATION F IN MO: Σ F 1-11 - MO								SUB-TOTAL REALIZATION SS: Σ SS 1-11 (%) REALIZATION SS IN MO: Σ SS 1-11 - MO
12.Light / sun-use & Protection								
13.Functions for building & roof								
14. Orientation & Sight								
15. Construction								
16. Costs & Finance & Benefit								
17. Architecture								
18. Sustainability								
19. Building Physics								
20. Fire protection								
21. Utilities								
22. Shape								
23. Material								
24. Users								
25. Flexibility								
SUB-TOTAL OBJECT F: Σ F 12-25 (%) OBJECT F IN MO: Σ F 12-25 - MO								SUB-TOTAL OBJECT SS: Σ SS 12-25 (%) OBJECT SS IN MO: Σ SS 12-25 - MO
TOTAL F: Σ F 1-25 TOTAL F IN MO: Σ F 1-25 - MO (%)								TOTAL SS: Σ SS 1-25 TOTAL SS IN MO: Σ SS 1-25 – MO (%)

Figure 101 MAF3; overview for all notated function-types (F) and sub-solutions (SS) by all Design Teams in one Design Task Setting

KNOWLEDGE-TYPE	SOLUTION-TYPE	TASK 2 XI XI.1, XI.2, XI.3, XI.*n*	TASK 2 YI YI.1, YI.2, YI.3, YI.*n*	TASK 3 XII XII.1, XII.2, XII.3, XII*n*	TASK 3 YII YII.1, YII.2, YII.3, YII.*n*
REALIZATION	FUNCTION-TYPES (F) (11)	*s* (*p*%)	*s* (*p*%)	*s* (*p*%)	*s* (*p*%)
	SUB-SOLUTIONS (SS)	*s out of ΣSS* (*p*%)	*s out of ΣSS* (*p*%)	*s out of ΣSS* (*p*%)	*s out of ΣSS* (*p*%)
OBJECT	FUNCTION-TYPES (F) (14)	*s* (*p*%)	*s* (*p*%)	*s* (*p*%)	*s* (*p*%)
	SUB-SOLUTIONS (SS)	*s out of ΣSS* (*p*%)	*s out of ΣSS* (*p*%)	*s out of ΣSS* (*p*%)	*s out of ΣSS* (*p*%)
TOTAL	FUNCTION-TYPES (F) (25)	*s* (*p*%)	*s* (*p*%)	*s* (*p*%)	*s* (*p*%)

Figure 102 Team Contribution Overview.

- Construct additionally the results of the Contribution Overview (Figure 99, page 199) and Team Contributions Overview (Figure 102) into a Practitioner Contribution Overview: this is the summation per practitioner-types in one team related to documented function-types and related sub-solutions (see Figure 103).
- When all practitioner-types of one Design Tasks are organized combine these results into the Practitioner Contribution overview for object- and realization-knowledge.
- Notate between brackets for each notated function-type and / or sub-solution: code of Design Team (A*n*), code of notated in the Morphological Overview (MO).

PARTICPANT TYPE	KNOWLEDGE-TYPE	TASK 2 XI XI.1, XI.2, XI.3, XI.*n*	TASK 2 YI YI.1, YI.2, YI.3, YI.*n*	TASK 3 XII XII.1, XII.2, XII.3, XII*n*	TASK 3 YII YII.1, YII.2, YII.3, YII.*n*
ARCHITECT	REALIZATION	*s (p%)*	*s (p%)*	*s (p%)*	*s (p%)*
	OBJECT	*s (p%)*	*s (p%)*	*s (p%)*	*s (p%)*
TOTAL ARCHITECT		***s (p%)***	***s (p%)***	***s (p%)***	***s (p%)***
CONTRACTOR	REALIZATION	*s (p%)*	*s (p%)*	*s (p%)*	*s (p%)*
	OBJECT	*s (p%)*	*s (p%)*	*s (p%)*	*s (p%)*
TOTAL CONTRACTOR		***s (p%)***	***s (p%)***	***s (p%)***	***s (p%)***

Figure 103 Practitioner Contribution Overview.

B CALCULATION

Calculation should be made on three levels: 1) Practitioner-level, 2) Design Task-level and 3) Workshop-level

1) Practitioner-level *(Practitioner Contribution Overview: Figure 103)*:
Calculate are the average notated knowledge types (object- or realization-knowledge) represented by function-types (F) / sub-solutions (SS) per practitioner-type (Pract. type p; Architect or Contractor) per Design Task *n*. (DT n). The result is the total amount of average notated function-types / sub-solutions per Design Task *n* in this calculation. The percentages are the results as part of the total results per Design Task Setting which is 100%.
This is represented in the following formula:

$$\text{Average notated, Pract. type } p = \frac{\Sigma \text{ notated F + SS per Knowledge Type}}{\Sigma \text{ notated Knowledge-types, all Pract. types per DT } n}$$

2) Design Task-level *(Team Contribution Overview: Figure 102)*
Calculated per Design Task:
- first; the average notated function-types (F) per Knowledge-type (K) object- and realization knowledge) per Team (T) as part of the possible notated function-types (Fref) from the reference list; as amount and percentage
- second; the average notated sub-solutions (SS) per Knowledge-type (object- and realization knowledge) per Team (T) as part of the total notated sub-solutions.

Use the results from the sub-totals and totals from the subsequent MAF3 per Design Task Setting.
For the notated function-types the notation is: *n* out of 14 (object-related), *n* out of 11 (realization-related). In brackets the % is notated. The total amount of notated function-types should be calculated as average notated for all teams per Design Task as a percentage of the total amount of function-types per knowledge-type (object-related: 14, realization-related: 11). For the all-over results the reference-list of 25 is 100%.
This is represented in the following formula:

$$\text{Average notated, T} = \frac{\Sigma \text{ notated F per Knowledge Type, all T per DT } n \,/\, \Sigma \text{ T}}{\Sigma \text{ F Reference-list all Knowledge Types}}$$

For the notated sub-solutions the notation is: *n* out of total notated sub-solutions per Design Task. In brackets the % is notated. The total amount of notated function-types should be calculated as average

notated for all teams per Design Task as a percentage of the total amount of function-types of the reference-list (100%).
This is represented in the following formula:

$$\text{Average notated, T} = \frac{\Sigma \text{ notated SS per Knowledge Type, all T per DT}n \,/\, \Sigma \text{ T}}{\Sigma \text{ notated SS all Knowledge-types, all T per DT } n}$$

Notated SS-type, DT n = Σ notated SS, K-type, Design Teams monitored

3) Workshop-level:
All workshop data need to be compared. So, by executing for instance three Workshops (or more) the results of the 3rd need to be used as a correction of the comparison of the other two. When there are only two workshops, the total number of scores per Design Task-level need to be divided by 2. The outcome is 'WS Total', which is an average result.

The outcomes need to be used for further comparison:
- Between practitioner-types (from the Contribution Overviews):
For comparison of notated function-types and specific object- and realization-knowledge by the different practitioner-types we can compare Architect and Contractor per Design Task. The results of the average score are notated object- and realization-knowledge of all Architects and Contractors per Design Task. For each practitioner-type the notated object- and realization-knowledge in function-types can now be calculated and compared.
- Between specific Design Task (from the MAF3 overviews):
The average notated scores per knowledge-type (object- or realization-knowledge) are the results per specific Design Task. The results for the sub-solutions the total amount of notated sub-solutions of all teams in for one specific Design Task. The overview gives a comparison of notated function-types and sub-solutions within Design-Teams in a specific Design Task. Percentages for function-types per knowledge-type are related to the total per object- (14) and –realization-knowledge (11) type of the reference-list (25 total).

The outcomes of these analyses should be presented to the applicants and discussed, examples of these graphical representations are presented in the result section of Descriptive Study II (Figure 69, page 149) and Appendix 11 (Figure 11.20, page 143).

***B* JUDGMENT**

The judgment should be executed on the outcomes related to the following two aspects:
1. Practitioner-type:
Important is if there is knowledge exchange between the Architect and Contractor during the design process and related to the Design Task. Because of the different knowledge domains, Architects have object-knowledge and Contractors have realization-knowledge with an overlap related to their competences. While the design-process and competences about design is not within the knowledge-domain of the Contractor the most positive result is that the Contractor contributes realization-knowledge. Also positive is the result when there is realization-knowledge contributed by the Architect, with or without the introduction of the realization-knowledge by the Contractor. It is judged as positive if the contribution of realization-knowledge of the Contractor increases in the next Design Task(s) of the Workshop. The following criteria for judgment should be used:
Negative: no contributed realization-knowledge by the Contractors or increase of amount of contributed realization-knowledge by the Contractor in the subsequent design-task.
Positive: more contributed realization-knowledge by the Contractor and Architect in subsequent design-task.

Most positive: more contributed realization-knowledge by the Contractor in subsequent design-task, compared to Architect.

2. Function-types / sub-solutions

Focus is on the contributed realization-knowledge, notated in sketches, notes and the Morphological Overview. For an Integral Roof Design related to the reference list is used to judge on the outcomes. Of this reference-list, 11 function-types are realization-knowledge and 14 function-types are object-knowledge related. This includes that the more realization-knowledge is explicitly used by both Architect and Contractor the most positive this is as a basis for the Integral Roof Design. In the judgment is also incorporated that no essential items should be missed related to the realization-knowledge. Related to the Design Tasks these function-types are: rain / water proof, temperature proof, ventilation, sustainable energy generation and construct & build. The following criteria for judgment should be used:

Negative: no contributions of notated realization-knowledge by the Architect and Contractor or increase of amount of notated realization-knowledge by the Architect and Contractor in the subsequent design-task.

Neutral: notated realization-knowledge by the Architect and Contractor and equal amount of notated realization-knowledge by the Architect and Contractor in the subsequent design-task.

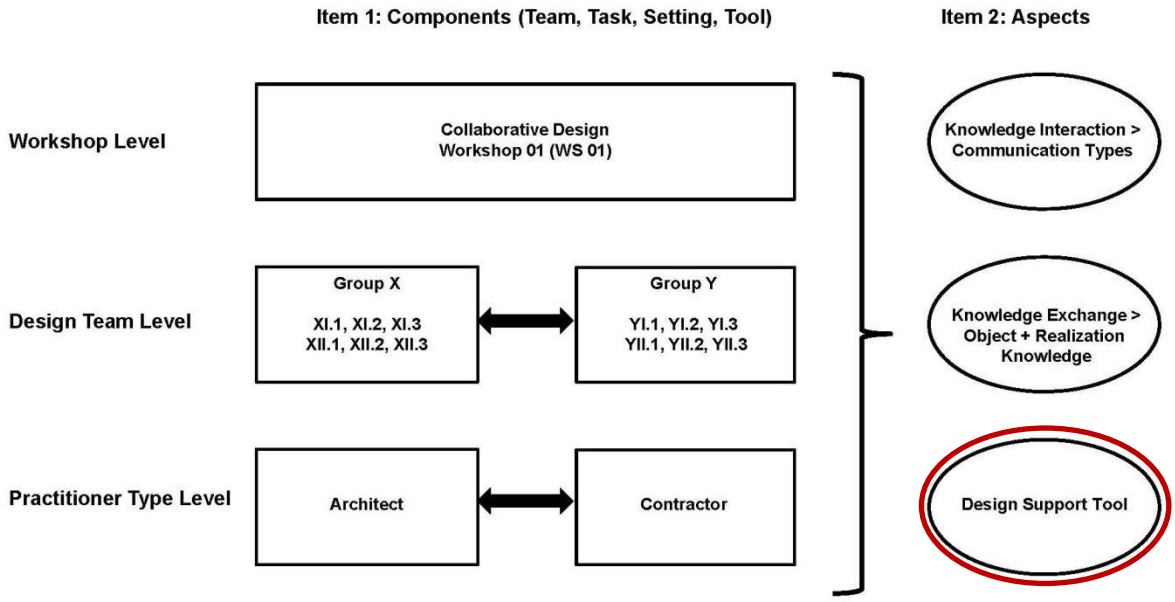
Positive: all essential realization-knowledge notated by the Architect and Contractor and more notated realization-knowledge by the Architect and Contractor in the subsequent design-task.

Most positive: all realization-knowledge from the reference-list is notated by the Architect and Contractor in the design-task.

ALL OVER REMARK

The more object- and realization-knowledge is *explicitly used*, the better the basis for developing an Integral Roof Design. Combined with the fact that the Collaborative Design setting is not a common practice it is positive when realization-knowledge is contributed at all. When there is less than half of the realization-knowledge of the reference list contributed in a team this the contribution is poor. Related to the different Design Tasks it is positive if the amount / percentage of contributed realization-knowledge increases in the following Design Task. Because to fulfill an Integral Roof Design aspects of coherency and completeness are essential but not part of the research project, a more detailed judgment related to the design is not possible.

C. The individual contributions, object- and realization knowledge explicitly notated in the Design Support Tool in a specific team; use of the MO.



Levels and items of comparison in observation and analysis

C STEPS

- Use the Contribution- and MAF3-overviews for all contributions as described in 2.above.
- Use only results of those Design Teams which used the Morphological Overview. (MO) Analyzed are only the explicitly notated object- and realization knowledge in the MO.
- Count for each type of practitioner and per function-type the amount of function-types / sub-solutions related to object- and realization-knowledge.
- Repeat the first 3 steps for those Design Teams where both Architect and Contractor use the MO
- Repeat the first 3 steps for those Design Teams where both Architect and Contractor notate realization-related function-types (F) and sub-solutions (SS)

C CALCULATION

Only those Design Task Settings were the MO is loose introduced are calculated. Calculation should be made on three levels: 1) Practitioner-level, 2) Design Task-level and 3) Workshop-level.

1) Practitioner-level *(Practitioner Contribution Overview, see Figure 103, page 202):*
Calculate the average notated knowledge types (object- or realization-knowledge), represented by function-types (F) / sub-solutions (SS) per practitioner-type (Pract. type p; Architect or Contractor) per Design Task *n.* (DT n). The results are the total amount of average notated function-types / sub-solutions per Design Task *n.* The percentages are the results as part of the total results per Design Task Setting which is 100%.

This is represented in the following formula:

$$\text{Average notated, Pract. type } p = \frac{\Sigma \text{ notated F + SS per Knowledge Type}}{\Sigma \text{ notated Knowledge-types, all Pract. types per DT } n}$$

2) Design Task-level *(Team Contribution Overview, see Figure 102, page 201)*
Calculate per Design Task:
- First; the average notated function-types (F) in the MO, per Knowledge-type (K) object- and realization knowledge) per Team (T) as part of the possible notated function-types (Fref) from the reference list; as amount and percentage.
- Second; the average notated sub-solutions (SS) in the MO, per Knowledge-type (object- and realization knowledge) per Team (T) as part of the total notated sub-solutions.

For the notated function-types the notation is: *n* out of 14 (object-related), *n* out of 11 (realization-related). In brackets the % is notated. The total amount of notated function-types should be calculated as average notated for all teams per Design Task as a percentage of the total amount of function-types per knowledge-type (object-related: 14, realization-related: 11). For the all-over results the reference-list of 25 is 100%.
This is represented in the following formula:

$$\text{Average notated, T} = \frac{\Sigma \text{ notated F per Knowledge Type in MO / } \Sigma \text{ T}}{\Sigma \text{ notated F per Knowledge-types, all T per DT } n}$$

For the notated sub-solutions the notation is: *n* out of total notated sub-solutions per Design Task. In brackets the % is notated. The total amount of notated function-types should be calculated as average notated for all teams per Design Task as a percentage of the total amount of function-types per knowledge-type (object-related: 14, realization-related: 11). For the all-over results the reference-list of 25 is 100%.
This is represented in the following formula:

$$\text{Average notated, T} = \frac{\Sigma \text{ notated SS per Knowledge Type in MO / } \Sigma \text{ T}}{\Sigma \text{ notated SS per Knowledge-types, all T per DT } n}$$

Notated SS-type, DT *n* = Σ notated SS, K-type, Design Teams monitored

3) Workshop-level:
All workshop data need to be compared. So, by executing for instance three Workshops (or more) the results of the 3rd need to be used as a correction of the comparison of the other two. When there are only two workshops, the total number of scores per Design Task-level need to be divided by 2.

The outcomes of the above analyses need to be compared for:
1. Practitioner-types (from the Contribution Overviews):
For comparison of notated function-types and specific object- and realization-knowledge in the MO by the different practitioner-types, notations by Architect and Contractor per Design Task should used. The results of the average score of notated object- and realization-knowledge in the MO, of all Architects and Contractors per Design Task is set at 100%. For each practitioner-type the notated object- and realization-knowledge in function-types need to be calculated and compared.
2. Design Tasks (from the MAF3 overviews):
The average notated scores per knowledge-type (object- or realization-knowledge) are the results per specific Design Task. The results for the sub-solutions the total amount of notated sub-solutions of all teams in for one specific Design Task. The overview gives a comparison of notated function-types and sub-solutions within Design-Teams in a specific Design Task. Percentages for function-types per knowledge-type are related to the total per object- (14) and –realization-knowledge (11) type of the reference-list (25 total).

The outcomes of these analyses should be presented to the applicants and discussed, examples of these graphical representations are presented in the result section of Descriptive Study II (Figure 77, page 160; Figure 79, page 162; Figure 81, page 163) and Example 7 of Appendix 12.6 (Figure 7.10, page 188).

C JUDGMENT

The judgment on outcomes needs to be done on the next two aspects:
1. Practitioner-type:
Important is if there is knowledge exchange between the Architect and Contractor during the design process and related to the Design Task through the use of the Morphological Overview. Because of the different knowledge domains, Architects have object-knowledge and Contractors have realization-knowledge with an overlap related to their competences. While the design-process and competences about design is not within the knowledge-domain of the Contractor the most positive result is that the Contractor contributes realization-knowledge in the Morphological Overview. Also positive is the result when there is realization-knowledge contributed by the Architect, with or without the introduction of the realization-knowledge by the Contractor. It is judged as positive if the contribution of realization-knowledge in the Morphological Overview of the Contractor increases in the next Design Task(s) of the Workshop. The following criteria for judgment should be used:
Negative: no contributed realization-knowledge in the MO by the Contractor or increase of amount of contributed realization-knowledge in the MO by the Contractor for the subsequent design-task.
Positive: more contributed realization-knowledge in the MO by the Contractor and Architect in the subsequent design-task.
Most positive: more contributed realization-knowledge in the MO by the Contractor in the subsequent design-task, compared to Architect.
2. Function-types / sub-solutions
Focus is on the contributed realization-knowledge, notated in the Morphological Overview. For an Integral Roof Design related to the reference list is used to judge on the outcomes. Of this reference-list, 11 function-types are realization-knowledge and 14 function-types are object-knowledge related. This includes that the more realization-knowledge is explicitly used in the Morphological Overview by both Architect and Contractor the most positive this is as a basis for the Integral Roof Design. In the judgment is also incorporated that no essential items should be missed related to the realization-knowledge. Related to the Design Tasks these function-types are: rain / water proof, temperature proof, ventilation, sustainable energy generation and construct & build.
Negative: no contributions of notated realization-knowledge in the MO by the Architect and Contractor or increase of amount of notated realization-knowledge in the MO by the Architect and Contractor in subsequent design-task. The following criteria for judgment should be used:

Neutral: notated realization-knowledge in the MO by the Architect and Contractor and equal amount of notated realization-knowledge in the MO by the Architect and Contractor in subsequent design-task.
Positive: all essential realization-knowledge in the MO notated by the Architect and Contractor and more notated realization-knowledge in the MO by the Architect and Contractor in subsequent design-task.
Most positive: all realization-knowledge from the reference-list is notated in the MO, by Architect and Contractor.

3. CD PROTOCOL 2.2 COLLECTED DATA FROM EVALUATION PRACTITIONERS

CD Protocol 2.2 covers the evaluation by the individual practitioners with the Workshop Questionnaire and Interviews after 6 months. First the types of evaluation used are described. Second the outcomes and judgment on these evaluation-types are presented.

EVALUATION TYPES

There are three types of evaluation which should be executed:

I Group evaluation

Executed during Workshop-session

- For Design Task 3, after the presentation of the designs by each Collaborative Design Team to the other practitioners, each team has to answer 2 questions:
    1. What is the difference of collaboration in traditional setting en working with the MO?
    2. How did you experience the use of the MO?
- All presentations should be video-taped; transformed to digital format; coding as for video-recordings
- Presentations should be are transcribed related to the 2 questions; put into one overview document; coding with Workshop number / design task number / Collaborative Design Team number

II Individual evaluation on the basis of Workshop-Questionnaire

The evaluation direct after Workshop-session (see Appendix 14, Figure 14.1, page 191);

- After the Workshop each individual practitioner should answer the pre-defined questionnaire, 11 questions with rating scale 1-5; where 1 is lowest rate and 5 the highest rate
- Each practitioner has to fill in his name, profession / function and years of expertise
- Within the research project each questionnaire should be coded anonymous; coding is profession (A = Architect, C = Contractor) and number of subscription
- All the results should be organized in a digital excel-overview-scheme:
    1. Scheme 1: overview of all individual practitioners, with coding system, questions and rating
    2. Scheme 2: general overview of average per practitioner-type; with coding system, questions and average rating

III Individual evaluation on the basis of the Workshop Interview

The evaluation 6 month after Workshop-session (see Appendix 14, Figure 14.2, page 191)

- 6 month after the Workshop an interview by telephone should be applied
- Interview with 4 pre-defined questions:
    1. Can you remember the CD-Workshops and the use of the MO; how did you experience both?
    2. Did you use the MO in the meantime:
    - yes, for which purpose, in which situation?
    - no, because
    3. If you used the MO; how where your experiences for yourself and for the other team members?
    4. Should this approach of CD and the use of the MO be stimulated in education for students and professionals?
- The interviews should be executed by trained assistants
- Interviews should be notated with name, profession and date; used in the research project anonymous with coding; profession and number of subscription
- Overview of interview-questionnaire should be organized in a table-document; questions and answers related to coded practitioner

OUTPUT AND JUDGMENT ON QUESTIONNAIRES AND INTERVIEWS

With the questionnaires and the additional interviews (after 6 months) the following aspects need to be analyzed and judged:

D. General insight in how the practitioners experienced the Workshop (Questionnaires: Q2, Q3; Interview: Q1).

E. General insight in how the practitioners experienced the use of the Morphological Overview during the Workshop (Questionnaires: Q1, Q4; Interview: Q1).

F. General insight in how the practitioners experience the use of the Morphological Overview in their own practice now, in the future and related to training / education (Questionnaires: Q5, Q6; Interview: Q2, Q3, Q4).

For the Questionnaires and the additional Interviews the following items are described: Steps, Calculation, and Outcomes for comparison, Judgment on outcomes.

II INDIVIDUAL EVALUATION: WORKSHOP QUESTIONNAIRE
On the basis of pre-defined questions direct after the Workshop

II STEPS

- Use the Pre-defined Questionnaire-Format (Appendix 14, Figure 19.1, page 191)
- The Pre-defined Questionnaire-Format should be filled in direct after the Workshop (day 2); check if all Formats are delivered, filled in correctly (rating scale 1-5), name of the practitioner.
- Collect all Pre-defined Questionnaire-Formats in an A3-portfolio with on the cover: Workshop-number, Workshop-date.
- Count the amount of delivered Questionnaires; notate the percentage of delivered Questionnaires.
- Make a Questionnaire overview.
- Vertical axis, in separate rows: the Workshop-number(s), practitioner-type numbers.
- Horizontal axis, in separate columns: the Questions Q1 to Q6 of the Questionnaire.
- Last row: average total rating for all specific questions.

II CALCUALATION

- Add the ratings per practitioner-type and per Question, divided by the number of practitioners which delivered the Questionnaire, this is the average rating per Workshop and per practitioner-type for the specific question.
- Add all ratings per question for all Workshops, divided by the amount of Workshops this is the average rating per specific question.

The outcomes give the following type of result use for comparison:
- Outcomes should be on the Likert-scale 1-5, which means the following rating for practitioners and score between brackets for researcher: 1: poor (2), 2: insufficient (4), 3: sufficient (6), 4: good (8) and 5: very good (10).
- General insight in how the practitioners experienced the Workshop (Questionnaires: Q2, Q3).
- General insight in how the practitioners experienced the use of the Morphological Overview during the Workshop (Questionnaires: Q1, Q4).
- General insight in how the practitioners experience the use of the Morphological Overview in their own practice now, in the future and related to training / education (Questionnaires: Q5, Q6).

II JUDGMENT

The judgment should be applied on the following two scenes:
1) *Within* a Workshop:
The outcomes between the different practitioner-types should be compared, especially the results of the Contractors. For the ratings of the Architect the assessors should keep in mind that for this practitioner-type, Workshop activities and the use of a Morphological Overview, is better known and more common practice compared to the Contractor. The following criteria for judgment should be used:
A positive rating of the Contractors shows that the Contractors have interest in working together with Architects.
A positive rating for the Workshops by Architects has the same impact but even more because this practitioner is more in the position to initiate a Workshop in a collaborative setting with the Contractors.
A positive rating for the use of the Morphological Overview by the Contractor implicates first, that Contractors are willing to use such a tool and secondly, that this tool is important for the Contractor to collaborate and contribute his specific knowledge. For the Architect should be considered that this practitioner-type is familiar with the use of Morphological Overviews and through his competence has his own tools which used in his own practice.
A positive rating of the Architects though indicates that they are not unwilling to work with a new Morphological Overview and that it is a help for them to work in a collaborative setting.

2) *Between* the Workshops:
All workshop data need to be compared. So, by executing for instance three Workshops (or more) the results of the 3rd need to be used as a correction of the comparison of the other two. When there are only two workshops, the total number of scores per Design Task-level need to be divided by 2.

III INDIVIDUAL EVALUATION: WORKSHOP INTERVIEW
On the basis of pre-defined Interview after 6 months.

III STEPS

- Use the Pre-defined Interview-Format (Appendix 14, Figure 14.2, page 191)
- The Pre-defined Interview-Format should be filled in by a trained assistant on the basis of the interview with a practitioner which participated in the Workshop, to be executed 6 months after this Workshop; check if all Formats are delivered, filled in correctly, name of the practitioner.
- Collect all Pre-defined Interview-Formats in the A3-portfolio with the corresponding Pre-defined Questionnaires, on the cover: Workshop-number, Workshop-date.
- Count the amount of delivered Interviews; notate the percentage of delivered Questionnaires.
- Make an Interview overview.
- Vertical axis, in separate rows: the Workshop-number(s), practitioner-type numbers.
- Horizontal axis, in separate columns: the Questions Q1 to Q4 of the Questionnaire.

III CALCULATION
- Outcomes which are related to a yes / no Question should be counted and divided by the number of interviewed practitioners. The result is the average percentage. However, these yes/no questions are only an introduction to the detailed questions which should generate outcomes as shown below.

The outcomes give the following type of result use for comparison:
- General insight in how the practitioners experienced the Workshop (Interview: Q1).
- General insight in how the practitioners experienced the use of the Morphological Overview during the Workshop (Interview: Q1).

- General insight in how the practitioners experience the use of the Morphological Overview in their own practice now, in the future and related to training / education (Interview: Q2, Q3, Q4).

III JUDGMENT

The judgment should be applied on the outcomes of the interviews by peer reviewers. The judgment is on the following two scenes:
1) *Within* a Workshop:
The outcomes between the different practitioner-types should be compared, especially the results of the Contractors. For the ratings of the Architect the assessors should keep in mind that for this practitioner-type, Workshop activities and the use of a Morphological Overview are is better known and more common practice for Architects compared to the Contractor. The following criteria for judgment should be used:
A positive rating of the Contractors shows that the Contractors have interest in working together with Architects.
A positive outcome for the Workshops by Architects has the same impact but even more because this practitioner is more in the position to initiate a Workshop in a collaborative setting with the Contractors.
A positive response for the use of the Morphological Overview by the Contractor implicates first, that Contractors are willing to use such a tool and secondly, that this tool is useful for the Contractor to collaborate and contribute his specific knowledge. For the Architect should be considered that this practitioner-type is familiar with the use of Morphological Overviews and through his competence has his own tools which used in his own practice.
A positive response of the Architects indicates that they are willing to work with a new Morphological Overview and that it is a help for them to work in a collaborative setting.

2) *Between* the Workshops:
Two main items should be compared: the experience of the Workshop and the experience, use and future value of the Morphological Overview. The answers of the Interviews have a more important weight on the importance and value of the Workshop compared to the Questionnaire because after 6 months the practitioners should have enough distance from the subjects. The following criteria for judgment should be used.

For the Workshop a positive rating in the Questionnaires means a majority (> 50%) of the practitioners which give a rating 2,5 or more on the Likert-scale 1-5, this when also a majority of the practitioners delivered the Questionnaires (Q2, Q3).

For the Interviews the following items are important: the majority per practitioner-type should respond (>50%), and a majority of responded practitioner-types should be positive in answering Question 1. This Question 1 has two parts; part one can be answered with yes or no, part two is a reflection on the Workshop. For the Morphological Overview a positive rating in the Questionnaires is a rating were a majority (> 50%) of the practitioners which give a rating 2,5 or more on the Likert-scale 1-5, this when also a majority of the practitioners delivered the Questionnaires (Q1, Q4 – Q6). For the Interviews the following items are important: the majority per practitioner-type should respond (>50%), and a majority of responded practitioner-types should be positive in answering Question 2 – 4. Important here is the argumentation of the practitioners why the Morphological Overview is has a positive or negative experience, if and why they use(d) or did not use the Morphological Overview in their own practice and what their opinion is about the training of the Workshop and the Morphological Overview.

In the Protocol Appendix 1 (page 196) the Time Schedule for organizing the Workshop is presented. In Protocol Appendix 2 (page 197 – 198) the Workshop Script is described.

PRACTICAL ASPECTS AND RECOMMENDATIONS FOR ORGANIZING THE WORKSHOP

In the following list the major highlights of the CD Workshop:
- Workshop: delivers a step-by-step approach to stimulate knowledge exchange for professionals in a multi-disciplinary setting related to complex design-tasks
- Tool: delivers a step-by-step approach to use a support tool to structure en exchange knowledge in this multi-disciplinary setting
- Setting: delivers a systematic approach and related tools for application in settings for the following multi-disciplinary context; in company, project-based teams, inter-disciplinary teams on different levels in organization, educational organizations (educators and students)
- Protocol: delivers a systematic model and appropriate formats to get insight and explicate key-aspects of interaction and knowledge exchange for multi-disciplinary collaborative design in different settings

Practical aspects and recommendations in organizing the Workshop:
- Setting: collaborate with the related professional organizations from the beginning to get insight into the specific aspects for: application, location-possibilities, competence-profiles and state-of-the art subjects
- Setting: for a successful setting it is important to have; an inspiring location which is easy to attain, an interesting program with state-of-the art lecturers for introduction to the subjects of the design tasks
- Setting: start in an early phase with the trained assistants; they are the support you need to organize in a good and smooth way the environment, equipment and to collect in a safe way the data for analysis
- Team: working with professionals is interesting but also demanding, they are busy and full of practical stress in content and time; make that they have an interesting time but also take care of the following aspects: check their application several times, make sure that they have the right competences, make sure to have a minimal number of professionals needed – it is better to have more than less! Make sure that you follow the scheme of change teams during the workshop
- Task: interesting and demanding tasks about state-of-the art subjects are essential to have an effective and successful workshop with professionals, make sure that you have enough background information about these subjects and tasks, a task should be demanding; this is a good mixture of the type and amount of information of the problem, the situation and the time available; the design-task should have a good mixture of complexity, vague problem-definition and expected result; presentation, discussion and reflection about the result and the process are an essential part of the success of the workshop for the professionals
- Tool: a step-by-step introduction in working with the tool is most effective for the practitioners, it is important that the practitioners of the teams discover, discuss and use the tool together; discussion and reflection related to the presentation of the designs by the practitioners will encourage the use and the learning effect; a comprehensive introduction about the content, the usefulness and the possibilities the tool offers in practice; use different type of practical examples in the introduction to illustrate these aspects

PRACTICAL ASPECTS AND RECOMMENDATIONS FOR THE ANALYZING FORMATS

In the following list the major highlights of the Analyzing Formats:
- Video Observation Format: delivers a graphical insight into the explicit contributions of object- and realization-knowledge by the individual practitioners in a team in the setting of a CD Workshop
- Video Interaction Format: delivers a graphical insight into the different types of interaction by the individual practitioners in a team in the setting of a CD Workshop
- Morphological Analysis Format: delivers a graphical insight in the explicit team contributions of object- and realization-knowledge in the setting of a CD Workshop
- The Improved Research Analyses Protocol: a step-by-step approach is delivered to get insight into several aspects related to the teams and practitioners: type and intensity of interaction, knowledge exchange related to object- and realization-knowledge, the available explicit knowledge, the process (flow, type) of interaction and knowledge exchange, the effect of a Morphological Overview related to these aspects
- Recommended for: practical multi-disciplinary settings with professionals on different levels of education and organizations; multi-disciplinary settings with students and researchers

Practical aspects and recommendations in using the Analysis Formats:
- Video Observation Format: to get an impression of the complexity it is wise to view the video first in total before starting the analysis and then use the time-sections as in the protocol; two minutes of video can contain a lot of information about interaction and knowledge exchange, use reference-list format to immediately notate coding function-type and sub-solution and send / receive (VIF); if possible use in the beginning a simplified format without the specific types of design (function, design-task, new to design task); for use in the next phase of analysis use highlight for the coding in the format
- Video Interaction Format: if possible use in the beginning a simplified format without the specific types of design (function, design-task, new to design task); use big-format of the VIF to count the different types of communication; use immediately the given format for this calculation as in protocol
- Morphological Analysis Format: highlight the coding related to the team and notated sub-solutions; this makes it easier to process for calculation

Practical aspects and recommendations in for Analyzing:
The aim of using the Analyzing Formats is to get insight into the interaction and knowledge-exchange between professionals with different educational background in CD teams. These Formats are relevant, systematic and effective as shown by application and testing. Although they are also related to a complex mixture of aspects (setting, team, task and tool) and subjects (interaction, collaboration, object- and realization knowledge, knowledge exchange). Therefore the following aspects in general:
- start to analyze one team with the Improved Research Analyses Protocol and related Formats; get used to the protocol; make a checklist of items related to the subjectivity of the interpretation of the documents and videos; the hierarchy and interrelation of the results of the three Formats and the time / planning related
- use the Improved Research Analyses Protocol team by team in total for one design task; this makes it easier to get immediately related result-checks for one team, gives the needed focus and concentration to do the analysis and avoids failures and therefore lot of extra work
- if possible: work with two analysts; because type of subject and data are complex; to have a second view and check on the analysis and results; to reflect on the results
- the results of the analysis are recommended for use of: the feed-back for the professional practitioners and teams in the Workshops, the Professional Organizations related to these professionals, researchers, lecturers and students on Universities and Knowledge Institutes

4. CONCLUSIONS, REFLECTION AND RECOMMENDATIONS

4.1 CONCLUSIONS

The outcomes of this research project show that it was possible, with the use of the Design Research Methodology, to develop a Technological Design in a transparent and step-by-step process with iterations, which can be used in a Practice Setting to stimulate interaction and knowledge exchange. With the developed formats – the Video Observation- and Video Interaction Format – it is possible to observe interaction and knowledge exchange between practitioners with different educational background as a basis for Integral Designs in the early design phase. The use of the Morphological overview as Design Support Tool show the possibility for stimulating interaction and knowledge exchange within certain limitations.

The motivation for this Technological Design was formulated as follows: there is a lack in practice of Collaborative Design scenes where practitioners – Architects and Contractors – can interact and exchange object- and realization-knowledge working on design tasks to produce Integral Designs that comprise realization knowledge.

The first aim was to investigate how and by which interactions the knowledge of both practitioners is exchanged in a Collaborative Design Workshop. The testing of the Definitive Collaborative Design Workshop and more specifically the use of the developed Video Observation Format and the Video Interaction Format shows, how realization-knowledge by the practitioners is exchanged and through interaction by speech or by notations on paper or by both to develop a design for a complex Design Task.

The second aim was that this Collaborative Design Workshop should facilitate a methodical introduction for knowledge exchange between the two practitioners in the conceptual phase for roof design. This aim is realized by the use of the Morphological Overview as Design Support Tool which was loose introduced in a design task in the Definitive Collaborative Design Workshop.

The observation and analyzing formats that are developed for analyzing interaction and knowledge exchange: the Morphological Analysis Format, the Video Observation Format, the Video Interaction Format and Evaluation Formats were tested successfully and function as adequate and accurate tools to analyze interaction and knowledge exchange between the two practitioners that execute a design task in the Collaborative Design Workshop. These formats generate valuable information and insights concerning interaction and the explicit use and exchange of knowledge by different practitioners during the design process.

The testing of the key-components and the related observation-, analyzing- and evaluation-formats in the Definitive Collaborative Design Workshop shows that it can be used successfully to facilitate exchange of object- and realization-knowledge for the Design Task as the basis for an Integral Design for roof. This confirms also the realization of the third aim: to test whether applications of the Definitive Collaborative Design Workshop by the practitioners stimulates the Integral Design for roofs by the contribution of realization-knowledge.

4.2 REFLECTION

The reflection concerns two parts. Part one reflects on the outcome *in* the research project: the results of the use of the key-components in the definitive Collaborative Design Workshop. Part two will reflect on the outcomes *of* the research project and the tests of the Definitive Collaborative Workshop.

First, concerning the reflection on the outcomes *in* the research project the use of the key-components which influence the Definitive Collaborative Design Workshops: the Design Task, Practice Setting, Collaborative Design Team and the Design Support Tool; the Morphological Overview.

When reflecting on the role of the ***Design Task*** it is effective to look if the complex design task is encouraging collaboration between the practitioners involved in the Definitive Collaborative Design Workshops; Architects and Contractors. Therefore the Design Task was organized as a 'pressure cooker' to enlarge the possible influences. The results show that a variety of media were used by both Architects and Contractors throughout the different Design Task Settings of the Definitive Collaborative Design Workshops. To determine the type of knowledge used in the design process for the Design Task in the Definitive Collaborative Design Workshop a reference-list was used derived from the competence-profiles of the practitioners. The results show that there is a wide variety of notated object- and realization-knowledge during the Definitive Collaborative Design Workshop; notated as function-types and sub-solutions related to this reference-list. The fact that realization-knowledge was notated to solve the Design Task in most Collaborative Teams show that complex tasks will encourage the needed collaboration between design and construct when organized in a Collaborative Design Workshop.

Two limitations need to be made concerning the collaboration process and result of the execution of the Design Task. First: the incorporation of object- and realization-knowledge through function-types and sub-solutions are the basis of an Integral Design. It cannot be stated that the results show that the solutions on the Design Tasks are Integral Designs because the necessary aspects of coherency and completeness were not part of the focus of this research project. Second: the focus was on the concept-phase of the design-process. To organize a real integral design process, many iterative steps have to be made and unknown variables can influence the design process and the realization in these phases.

However, what can be stated is that if collaboration on the complex Design Task between Architects and Contractors is effective in the beginning of the design-process, the influence of the design-information will also be most effective.

In the research project a face-to-face setting was used as a ***Practice Setting*** to exchange object- and realization-knowledge between practitioners, but was it effective and realistic enough? The Practice Setting was organized in a way that it could function, as the results show, as a realistic setting for the practitioners with different educational background on interaction and knowledge exchange. Characteristics of the practice setting as defined by Emmitt (2010) and settings for training and education (Bierhals et al. 2007) were used to ensure the right Collaborative Design scene. The organization of the Definitive Collaborative Design Workshop was managed with the help of the Professional Organizations and trained assistants. Assuming that a face-to-face setting should manage the most encouraging environment for interaction and knowledge exchange the research project focused on the explicit use and notation of object- and realization-knowledge by speech, notations and the Morphological Overview. The results show that in all different Design Task Settings collaboration took place. Although, the Architects took in some Design Task Settings a more dominant role, the Contractors could communicate a significant ammount of function-types and sub-solutions in all settings. Significant is that although the majority of the notated itmes were notated by the Architect, the Contractors could put forward additional function-types and sub-solutions which were also notated. This shows that a Collaborative Design Workshop can provide both Architects and Contractors a

setting to exchange and notate effectively their specific knowledge; object- and especially realization-knowledge.

Related to the success of the setting the following remarks have to be made. First, as mentioned already the research project tried to minimize the influence of the researcher by working together with the Professional Organizations, the Technical University of Eindhoven and trained assistants. Also a script was made and used for the organization of the Definitive Collaborative Design Workshop, for the Professional Organizations and for the tasks to perform by the trained assistants. Although for the Definitive Collaborative Design Workshop two complete workshops were executed and additionally a similar third Definitive Collaborative Design Workshop was planned in April 2010 after the second one in June 2009. Due to practical problems with the Professional Organizations the Lay-out could not be fulfilled in the same manner and with enough practitioners. This could also be an indication of the factor of overuse of the workshop as mentioned by Emmitt (2010, page 75) and that education and training on Collaborative Design processes are still not common practice (McPeek & Morthland 2010). The second remark related to the success of the setting is related to the competences of the practitioners. By organizing the Definitive Collaborative Design Workshop with the Professional Organizations it was necessary that these organizations would be the 'filter' to verify the 10-years of experience of the possible practitioners. Although this was planned and part of the procedure the research project had no influence on the final check of this verification. The use of the application-formats within the Definitive Collaborative Design Workshop did not identify 'fault' subscriptions but could not be verified with an extra check for reasons of privacy. A remark should be made by the possible influence of the different practitioner-types. It was observed and analyzed that the Architects showed to be in majority the practitioners that were notating the items which were exchanged and discussed by the team-members. Although it could also be observed that Contractors were introducing function-types and sub-solutions which were notated by the Architects, it was also observed that some items were not notated by them. In these situations the Architect might be defined as a, sometimes, negative filter for the contributions of the Contractors. This limitation might be strongly related to the difference in educational background of the different practitioners involved and can likely be avoided by extra training.

The Practice Setting of the workshop as tested shows to be a suitable situation, compared to real practice, to stimulate interaction and knowledge exchange between the different types of practitioners in a Collaborative Design Workshop.

The third key-component which can influence the Collaborative Design Workshop design is the ***Collaborative Design Team,*** which has to be competent enough to exchange object- and realization-knowledge. This was determined by the individual contributions of notated object- and in particular realization-knowledge and was an indication of collaboration between competent practitioners. As shown in practice the need for the incorporation of realization-knowledge in the design-process in an early phase of the design is one of the aspects which are the basis for an Integral Design for roofs. The results show that in all the Design Task Settings both practitioner-types could introduce and contribute realization-knowledge, especially when the Morphological Overview was introduced compared with the Design Task Setting where the Morphological Overview was not introduced.

Two aspects play an important role in analyzing these contributions. First, the research project only used notated items to determine the contributions of the practitioners. This was done for two reasons. Only the documented items are explicit in the knowledge exchange through the design-process and because only documented items can become task-related knowledge for other practitioners and teams in the (design) process. Second, stated was also that not only the amount of contributions are important but most of all the content of the contributed and documented items. The documented items should be related to the Design Task and to the knowledge background of the practitioners.

When discussing the two aspects related to the contributions the collection of the data is the first step. This was done by the documented items of the teams, photographs, with video-recordings and a global viewing during the Definitive Collaborative Design Workshop. By using different observations and data-collecting by trained assistants a one-focused view was avoided, although only the researcher used the developed observation- and analyzing formats for determination and analysis. This rich data-collection could only be analyzed in a fine-grained way by using different observation and analyzing-formats. The validated formats of 'Bales and the Protocol Analysis were studied and lessons learned were used to develop two formats within the research project to do this fine-grained analysis: the Video Observation Format and the Video Interaction Format. In combination with the Morphological Analysis Format the data could be determined and analyzed efficiently on the *what, how, who* and *when.* Although these formats could be used to get the aimed results it cannot be stated that these formats can be used directly as a method. The protocol for the use was used coherent but for complete validation future application in practice is necessary.

The fourth key-component of the research project was the ***Design Support Tool***; the Morphological Overview. An important aspect to the use of the Morphological Overview is how practitioners, defined as competent and with a clear need for learning and reflection (Figure 12, page 59), would accept this tool. The current research project shows that when the Morphological Overview was used the practitioners had a learning-by-doing attitude (Schön 1987) and although practitioners did not adopt the Morphological Overview in the strict methodical way, they were eager and able to work with the tool in the specific context (Kolb 1984, Jarvis 1995). The research project shows that the Morphological Overview was used by a majority of the teams and practitioners. Of Architects 76% used the MO and 35% of the Contractors used the MO. When the MO was used of all notated function-types about three quarter was also notated in the MO and about a third of all sub-solutions. What could also be determined is that in the Morphological Overview both object- and realization-knowledge was notated by Architects and Contractors. Also could be determined that in 3 out of 17 Design Teams both Architect and Contractor used the Morphological Overview to notate object- and especially realization-knowledge. So, this confirms the former research of the BS research group as presented in the introduction section and that the MO can function as a Design Support Tool as described by Lindemann (2003) and explicated on page 23 of this chapter..

Some limitations have to be made. Overall only a limited part of all possible function-types and probable sub-solutions were notated in the MO and when introduced the second time the MO was use by Contractors less compared with the other Design Task Settings. This shows that the successful introduction and use of a new supportive tool in a Collaborative Design Workshop is not easy. Some important aspects can be mentioned here. First, the use of a new Design Support Tool is not common in practice of the Dutch Architect. In a Collaborative Design Workshop where an Architect has to work with other practitioners with no or poor design-experience such a Morphological Overview could improve the interaction and knowledge exchange in notated object- and realization knowledge to solve the Design Task. That this is a realistic approach can be observed by the result of the Design Task Setting of group X. The outcomes for this group X show that in the step-by-step approach to design collaboratively on a design task with the Morphological Overview is a very effective way for contributions in general and realization-knowledge and Contractor-contributions in particular. Second, when reflecting on the use and effect of the Morphological Overview and to avoid emotional impact (Loosemore 1998) three methods were used; notations of the trained assistants, the questionnaire directly after the Workshops and an interview after six months by the trained assistants. Although this is a careful approach the influence of socio-emotional aspects is always a factor but could not be determined within the scope of this research project.

Two specific benefits of the Morphological Overview can be articulated. First benefit is related to the requirements for support tools as defined by Lindemann (2003). As a Design Support Tool it showed to be flexible and adaptable in use for the practitioners involved and was relatively easy to learn and use for both Architects and Contractors. Additionally it could be determined that it could be applied to

support communication and visualization of mental ideas and images by both practitioner-types. The Morphological Overview could also be used to structure topics (function-types) and solutions (sub-solutions). Although, the use and learning was not all over positive it can be stated that the Morphological Overview fulfills the majority of the requirement of a successful support tool. Second benefit is related to the content of the use of the Morphological Overview; because of the structured and transparent way the tool can help the practitioners to put forward and notate object- and realization-knowledge in a Collaborative Design Workshop; it can be the basis for the development of an Integral Design.

The results of this research project show that with the Collaborative Design Workshop the flow of knowledge exchange of explicit notated object- and realization-knowledge between two practitioners can be improved and that the interaction in this collaborative scene can be stimulated to improve this flow. Additionally the results show that with the loose introduction of the Morphological Overview as a Design Support Tool has a positive effect on, the knowledge exchange and especially the exchange of realization-knowledge by Contractors. Additionally the positive and negative aspects of the developed Collaborative Design Workshop could clearly be determined.

Part two will reflect on the outcomes *of* the research project and the tests of the Definitive Collaborative Workshop. With the Collaborative Design Workshops an appropriate Practice Setting to stimulate practitioners with different educational background for interaction and knowledge exchange could be developed and tested successfully. Simultaneously the Collaborative Design Workshop could be used efficiently as a setting to observe the interaction and knowledge exchange for the research project. Towards the setting and the observation the following remarks can be made.

The first remark is the role of the facilitator and researcher. In this research project the facilitator of the Collaborative Design Workshop was also the researcher. To manage the role of facilitator, a specific role was necessary (Emmitt 2010, page 74) and applied. To avoid influence of the researcher in the role of facilitator the Collaborative Design Workshop script was developed and trained-assistants were used. The managing of the Collaborative Design Workshop was therefore strict, included the loose introduction of the Morphological Overview and the week in between the second introduction of the Morphological Overview. This was done to avoid an overuse of the similar approach (Emmitt 2010, page 75). The observations and the data-collection of the scene were organized and executed by the trained-assistants. Through these task-related managing of the Collaborative Design Workshops the risk of influencing the scene and the results was decreased within the context.

Second remark is on the restrictions in reality the choice of the Collaborative Design Workshop as a semi-experiment setting was a working alternative. There are some items to discuss. First, the semi-experiment is used to focus on specific aspects of Collaborative Design; interaction and knowledge exchange between Architects and Contractors. As mentioned in the introduction chapter, many other variables are affecting a Collaborative Design process which characterize design projects (page 3-4) and communication (page 14-15). The focus of this research project could determine valuable insight into task-based results of feedback in interaction of knowledge. Additional research which can relate these insights to other e.g. socio-emotional variables can broaden the practical scope. Second the setting was focusing on face-to-face, Collaborative Design scene at the same place and with a manual Design Support Tool, without the use of ICT Design Support Tools such as BIM (Building Information Models) which are used more and more in asynchronous Collaborative Design scenes. On the one hand this research project could show the importance of the face-to-face scene for training and stimulate Architects and Contractors on Collaborative Design processes to put forward, discuss and notate explicitly their knowledge. Additionally in this scene it could be determined that rather easy to use Design Support Tool, the Morphological Overview, can improve the interaction and knowledge exchange for object- and especially realization-knowledge in the early phase of the design. These insights are valuable to use before or in combination with the other more sophisticated Collaborative Design scenes. This to have a more optimal starting position and insight, roles and competences for

the practitioners involved in the different teams. This finally to interact and exchange efficiently the necessary function-types and sub-solutions of object- and realization-knowledge for an Integral Design. Third item is related to the application of the Collaborative Design Workshop. The setting was applied two times. This was due to the fact that organizing the Collaborative Design Workshops had to rely on free subscription and availability of practitioners and support of the Professional Organizations. Within the planning of the research project a third execution of the Definitive Collaborative Design Workshop could not be realized with enough competent practitioners. This experience shows that there is always a critical balance between the practice and research in a Technological Design. Fourth item to discuss is the introduction of a Morphological Overview in the Collaborative Design Workshop which should encourage collaboration by supporting a more methodical and structured way of working. Possessing sufficient knowledge is not sufficient to function as a competent member of a design team. The ability to communicate this knowledge in the right way and the right time is essential. This implies that the inclusion of training on communicating within collaborative teams should be a prerequisite of the education of many design and building related practitioners. This research project shows that with competent practitioners these Collaborative Design Workshops are an effective and structured way to work collaboratively on complex design tasks.

Third remark is on the developed formats; the Video Observation Format and the Video Interaction Format. These formats are important to observe and analyze the interaction and knowledge-exchange between the practitioners by showing content and type of interaction in a schematic and graphical way in two schematic formats. Because by using these formats applied in the Improved Research Analyses Protocol in a Practice Setting of a Collaborative Design Workshop it can be made explicit how collaboration develops in time and if this affects interaction and knowledge exchange between the practitioners in the team related to the: *what, who, how* and *when*. With the Video Observation- and Video Interaction-Format complementary to the analyzed communication of the Protocol Analysis or Bales' Interaction Process Analysis, the explicit notated knowledge-exchange by the practitioners on the design can be determined. However the following remarks should be made. First, by using the Video Observation – and Video Interaction Format it became apparent that per video-recorded hour at least 12 hours is needed to transcribe, prepare and analyze the formats, all video-recordings of the 24 teams within the Definitive Collaborative Design Workshops were analyzed. Although this is time-consuming through the use of the developed protocol and with the developed formats it was possible to give a fine-grained insight into the interaction and knowledge exchange between the involved practitioners. Second remark is on the use in practice. Within the practical setting of the research project it was not possible to test the formats with other researchers and determine the impact of own interpretations of the researcher(s) on data and classification as indicated by Emmitt and Gorse (2003). The application of the developed formats by other researchers should offer a more extended insight on Collaborative Design Workshops based on more workshops with practitioners. The Video Observation- and Video Interaction Format can be used to observe and analyze the use of tools, media and roles between two practitioners in collaborative teams.

4.3 RECOMMENDATIONS

Additionally the following recommendations can be made.

The First recommendation concerns the collected data. Because in this research project a large amount of data about collaborative teams is collected, it is useful to use this data for several additional or other type of research. One field of research could be a more multi-disciplinary research which could enrich the insight of working together in small collaborative teams. Where the current research had its limitations in looking at a fine-grained analysis on interaction and knowledge exchange during collaborative executed design tasks, the use in other fields might provide interesting contributions. Additionally and complementary the formats can be useful for the following purposes. First: to show graphically differences in interaction and knowledge exchange in design processes. Second: to identify and determine skills and knowledge related to competences of practitioners as the influence of activity types within this setting. Special fields of interest are Knowledge Management, Social Sciences and Linguistics.

A second recommendation is related to the Morphological Overview. The Morphological Overview showed its effect within the practice setting. This provides evidence and support for the future use of the Morphological Overview by practitioners with different educational background in Collaborative Design Workshops. The recommendation is to develop a three-step format which starts with the Morphological Overview as basis for a design in the early design phase, in collaboration and including realization-knowledge. The second step is a notated reflection on this step which can lead to a feed-back chart as third step and basis for the next design phase.

The third recommendation concerns the development of the integral approach for knowledge development on Collaborative Design processes. This should be organized by connecting knowledge from practice, education and research in the field of design and construct. Future collaboration between Professional-, Research- and Educational Organizations should encourage this approach and could be part of the Dutch approach as proposed by Eekhout (2009). .

The fourth recommendation concerns the scope of the research project: the context of the Dutch Building Industry. The data and results of this research project are representative for the Dutch building culture which is specific because of the language, the way of collaboration incorporating interaction and knowledge exchange, related to local settings and conditions. By organizing such Collaborative Design Workshops for teams from different nationalities using the English language, one might create an interesting cross-cultural comparison concerning differences in interaction and knowledge exchange. .

A final recommendation should be made regarding the model for the Collaborative Design Workshop. A step-by-step approach is most optimal to stimulate interaction and knowledge exchange, especially realization-knowledge, between practitioners with different educational background to work collaboratively. Therefore it should be considered seriously to implement this Collaborative Design Workshop in the educational training for students and practitioners. The use of Collaborative Design Workshops might also be appropriate for training and education to Lean Construction and management as being a Collaborative Design process of designing and creation of artifacts. Research to the practice of Lean Construction and management show lacks in understanding and implementation of the lean principles in construction (Salem et al. 2005; Jørgensen, 2006, Winch 2010; Koskela 2011). This is especially important related to Architects which could have a more positive influence on the collaboration by sharing their design experience. This experience should better be coupled to a methodical way of working which supports possibilities for other types of practitioners to effectively exchange their knowledge.

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ACKNOWLEDGEMENTS

….
Foliage of lightning,
geometries of echoes:
on a leaf of paper
the poem constructs itself
like day
on the palm of space.

Octavio Paz; The Everyday Fire

If life can be seen as a journey, this journey I undertook to do a PhD-research is one which gave form to my life. Actually this journey was born out of two aspects in my life; 'creative wonder' and the role of 'the master'. These aspects are the main influences and so they are the two lines in which this acknowledgement is composed. Through this text I want to thank all the people which took and take this journey with me.

Creativity and wondering are two characteristics you are born with, the only thing you have to do as a human being is to cultivate this creativity and wondering by learning about it and practice it as much as you can. I was lucky to discover my own creativity in my very youth, by just looking at the world, start to wonder and then try to capture this wondering through designing. Starting with pencil until the pencil is part of your own feeling and body, and then take a next step. Through taking these steps each time a new part of the surrounding world and my own world would open up. This wondering and drive to work with this creativity fills me with a great joy; the joy of working with my hands, with materials, colors, stuff and creating things. Through this journey I discovered many other worlds of interest; art, poetry, music and later architecture. The art of the master made and makes me wonder every time I experience the works of them. The first time I experienced the paintings of my grandfathers' brother Eugène Quanjel, the first time I felt the poetry of Lataster, the first time the wondering and power of Picasso. The poets which are the masters of the word; the humbleness of Willem Hussem, the wondering of Octavio Paz, and the overwhelming worlds of Lucebert. The music that got me as soon as I heard Aretha Franklin and Stevie Wonder – yes you can dance to it. Discovering further, the smash in the face of Live Evil by Miles Davis. The wondering worlds of all those wonderful musicians I could experience life in different settings; improvised music, instant composers. What it's like to be a true master: to listen to others and to be able to play in 'any position'. And finally the experience of space – a medium I discovered I could manage – of architecture. That started with an uncle of mine Gène Quanjel, an architect and priest. The first experience was when I was 6 years old and visiting with him the Cloister of Vaals by the great architect Dom van der Laan. I knew that this was a thing I wanted to work on. From there on the road on studying architecture started. From the start of wondering also the importance of the true masters which could teach me began.

Studying at both HTS-Bouwkunde as well as Architecture at the Delft University of Technology was, and still is, for me an important back-up for learning about the total scope of designing and building as part of our environment. Important as an architect is each time, to imagine that with the act of designing you also have to imagine *how to make* the design in practice. My background, say my roots, are both; my mothers' family stands for the more practical side of the building industry, where my father' family is more about the creative aspects of building. So my grandfathers and grandmothers were my first private masters.

From the moment that I did my practical studies at the HTS-bouwkunde I knew, through the atmosphere of within the offices and projects of working together – each with his own knowledge and

skills, that this was my ‘thing. Working at the office and with Arno Meys was a magnificent experience where I could view what was necessary to achieve and work on architecture. From 1989 I was lucky to work and develop my knowledge and skills in two big and professional Architectural Offices. At Architecten aan de Maas I could work immediately on complex projects and direct with another master architect; Gerard Passchier. But also working with a real professional organization and professional team’s right from the start. And to construct the buildings of course as I could experience with another uncle of mine Thieu Houtackers who showed me how difficult this is and how much endurance it takes. The next step was with BroekBakema Architecten, an office with a big tradition and development. They gave me the opportunity to develop and to experience. Through the different type of projects in scale as well as in type I could experience what it is to design, develop and construct an interior, building or urban plan within different settings with professionals, clients and users. The trust and cooperation I owed from Jan van Iersel gave space for this development. But very important were all those professional colleagues I could work with within and outside the office. Especially the team I could work with through the years and made it a wonderful experience with many beautiful and satisfying buildings. I learned a lot about managing and execution of the design and construction by two true professional masters: Antoon Ceelen and Peter van den Berg.

From there on the fascination of developing my own knowledge and skills grew further, say more idealistic, in that of knowledge development within the Architecture Office and the Building Industry. This was leading towards a situation where I, next and in interaction with the projects I did, started doing research with colleagues and specialists / consultants related to architecture, construction and climate. This fascination is something from ‘within, say the passion for architecture, but also driven by the situation within the Dutch Building Industry; how I experienced this through my own projects and the broader scope and developments in the field of Architecture and Practice. Working on my own competences to ‘makes things better’ was an ongoing process in projects as well as studies, competitions and small research programs. This I developed through many projects within my own office of working together with others like Stephen Lewis, LIAG Architects or recently with Atelier PRO as a senior architect on the Meander Hospital.

During one of my projects, the design for main office for Kropman in Utrecht Leidsche Rijn, I met Wim Zeiler as a client as well as a professional climate advisor. From this moment on, the development of ‘working at the professional aspects’, got an extra flow. This resulted into a very interesting project were Wim and I with many other professionals and students were able to develop innovative construction and installation aspects within the primal design phase. This project got the Project Demonstration Status for the Ministry of Economical Affairs in the setting of the IFD-project (Industrial Flexible Durable design / build). Even more interesting was the start of the research-program Integraal Ontwerpen which we did together with Peter Luscuere and Fons Verheijen in commission of the Technical University Delft, the TVVL and the BNA (2000-2003). Through this research, I examined the influences and mechanisms within the Dutch Building Industry and especially between architects and HVAC-advisors and could come up with ways of ‘changing the culture’ of these professional groups in order to improve their knowledge and skills for working together; the Integral Approach. Through this study I got involved even more in the world of practice, education and research within my profession as well into the world of that of Wim Zeiler, which I owe much respect.

The research Integraal Ontwerpen ended in 2003; first there was no ‘follow-up. In 2004 Wim Zeiler asked me to work as a PhD at a research-project derived from the Integraal Ontwerpen-project. My work for my own office was too demanding so I introduced Perica Savanović to Wim Zeiler. Perica got the new PhD-candidate who took the advantage of working on this subject. In 2005 there was the possibility to work on the subject of Integral Design in relation to Architects and Contractors, this time there was this ‘trigger which is related to the back-ground I described above. From there on I started with the research laid down in this thesis and which became a journey and friendship with Perica. His humor, intelligence was and is a great inspiration for me.

At the start of the PhD and strongly involved in the subject and our team I was able to work with Henk Trum. He was a great help and example to me. Unfortunately, due to personal circumstances, Henk Trum could not be my academic supervisor. For me Henk Trum is a true master in the sense of the eastern philosophy; 'humble, with great conviction and intelligence.

A key-figure and important professional on this routing became Ad den Otter as my academic supervisor and a good guider on the level of research, education and practice. Ad was always there when needed with advise, constructive critic and support. Ad supported and encouraged me throughout the last phase of this PhD process. Beside of that, Ad is a wonderful person with a great character and I'm glad that we can continue our journey through the collaboration within ADMS (Architecural Design Management and Systems).

Another important professional on my journey was Duncan Harkness as an academic writer and text-corrector. Duncan supported me at the starting point of the writing of the Thesis not only with his masterful structuring and logic but also with his humor.

Through my research members of the committee were of great importance. Right from the beginning of the research Integraal Ontwerpen in 2000 I met Peter Luscuere as a professor at the Technical University Delft. As a master of another world – the world of technology, engineering – he is a really amazing and inspiring person. I have great respect for him as a person and true master. On an academic level the door 'opened for me through the acquaintance with Harry Timmermans from the Technical University Eindhoven; a great academic researcher and thinker: 'in control, with patience, focused and with great analytic sensors and comment. Professor Joop Halman of the Twente University of Technology I knew less, but his work, background and amazing field of experience makes it an honor to have him as an important member of the committee. During the years and especially through Ad den Otter and the work with CIB (International Council for Research and Innovation in Building and Construction) I met Stephen Emmitt. I studied already much work of Stephen which developed an important fundament for coupling of knowledge management and architectural practice. It is a great honor to meet, discuss, learn and work with someone like Stephen who as an architect, educator and researcher is a true example.

On this routing I was glad to meet and work with many professionals from different disciplines as well as the professional organizations of the TVVL, BNA, Hellend Dak and Vebidak. I want to thank especially Jos Bijman, Jos Habets and Jan Weijers for their ongoing supports during this process. Part of the research was done within the 6th European Task Research EuractiveRoofer in collaboration with TNO Bouw en Ondergrond. Through the years it was a pleasure to work with and to get professional support from Wouter Borsboon and Chris Geurts. Many other professionals were an inspiration and help, to name just a few: John Habraken, George Ang, Hennes de Ridder, Mick Eekhout and Jos Lightenberg.

During my part-time PhD I worked as an architect. As time evolved I combined this practice with a job as program-director of Bouwen met Groen en Glas. This was a National Program initiated by SIGN / InnovatieNetwerk en Productschap Tuinbouw and had the aim to investigate, study and stimulate new directions, possibilities and techniques in application of nature into the built environment. Part of this job was organizing different kinds of collaboration between other programs, organizations, firms and practitioners. Through this routing I organized also the collaboration with a similar program in Noord-Brabant with Willem den Ouden as program-director. Out of this collaboration, and by reference of Willem, I could apply for the job of Professor (Innovation Building Process & Technique) at Avans Hogeschool, University of Applied Sciences in 2011 (Built Environment & Infrastructure: AB&I). Although the timing related to my PhD could be more optimal this was the start of a magnificent and unique process in working on the development of professional competences through connecting education, research and practice within my field of experience. I'm very glad and happy to work with so many inspired and motivated professionals on this task. The culture and colleagues within Avans

and AB&I is great, the list of people who I want to thank too long. Regards to the members of the Executive Board of Avans; Paul Rüpp, Marja Kamsma and Frans van Kalmthout, for their trust, confidence and opportunities. Special thanks to the 'A-team members: Lisje Schellen, Marjo Stevens, Esther van der Ham, Sandra in 't Groen, Joop de Zwart, Maarten Rutten, Carel Geenen and Tom Kretschmann,

Not that it was all work, not at all. During the years many of my colleagues became friends. But studying and living in Delft for all these years I met many; Ellen Bisschoff, Reinier Witteveen, Werner Schoeman, Jeroen Heitzmann to name just a few. Very important are also my friends from the Lions in Delft which became a good environment and support for all aspects of life. Here I became friends with Marc and Lenneke van Pelt, Joep and Annemarie Brouwers and many others. Especially I want to mention here Martin and Ine Lagendijk who are so wonderful, lovely and brave persons. With Martin I spent many hours of discussion about the quality of life and profession. It is a great loss that he died in April 2011, a good friend and example.

As I mentioned in the beginning; my family is the foundation of what I could become. I'm glad that I could grow up within such a warm, social and lovely family in the broad sense; from grandparents, aunts and uncles, nephews and nieces. I thank all of them, especially in honor of my grandma's Quanjel-Bauer and Houtackers-Peters; Tance Houben-Quanjel, Lies Houtackers, Resie Houben and Josette Houtackers. Great love and joy I get from my brother Chrétien and his family, especially Renée and Thijs. My 'new' family-members became a natural part of my life; thanks Wilfried & Linda and Jürgen & Ellis and Rosemarie & Karel. However, my closest love and appreciation for all they did and do go to my parents: Alda and Jo, you give love and warmth to grow (it still does)!

As there are masters of live throughout all the years within my family I am very lucky to have such beautiful friends. Not at least through my wife Marilyn; Ingrid & Edwin, Tanja, Monique, Sabina & Diego and Saskia & Niels; thank you all for your love and support! Throughout the years my closest friends were my anchor-points and inspiration. During the Delft-studies I became very close friends to Tom and later to his wife Liene; each time we met they show me the wondering of life, enjoying it and share it. Through the years at Broek and Bakema, I met Han and Yolanda, who became a magnificent couple and friends; they are an example to me how to succeed and put strength out of love. Two very special friends are Luc and Ruud. I grew up with them from childhood, as companions, as closest friends, as brothers. We share a life of trust, joy, wondering, experience to life and arts. With their wives José and Petey we share families; Luc and Ruud thanks for being there, you are masters of 'outha space!

When there is family and friends you are lucky, when you have the love in another person you are more than lucky – you are happy. In 2005, shortly after I started my PhD, I met the love in another person: Marilyn. She is a true gift to me and to my life; her intelligence, creativity and love is an everyday inspiration and support – an everyday fire.

Acknowledgement for Financial Support

This PhD-research was possible thanks to the financial support of the following organizations: KCBS, WOI and the Foundation 'Stichting Promotie Installatietechniek' (PIT).

CURRICULUM VITAE

Emile Quanjel was born in Heerlen on September 1, 1961. In 1983 he graduated the HTS Bouwkunde (Construction Engineer) and with honorable mention he graduated his final studies with prof. ir. H. Hertzberger on the Technical University in Delft (Architecture) in 1989. From that moment on he worked for several middle-sized Architectural Offices in the Netherlands. From 1989-1990 he worked as architect with Architecten aan de Maas (Maastricht – Rotterdam) and form 1991-2000 as project-architect at BroekBakema Architecten (Rotterdam). In 2001 he started his own Architectural Office in Delft and worked as architect-associate with Stephen Lewis x Associates and as senior-architect for LIAG-Architects (Den Haag) and Atelier PRO (Den Haag). His practical experience covers the whole building-process from interior-projects, complex-utilitarian building-projects and master-planning for private as well as professional clients in different organizational contract formats. Currently he works as senior-consultant and senior-architect.

Parallel to his practical experience he is involved in education and research. From 2000 on he was a lecturer and mentor for different educational institutions in Rotterdam and Delft. From 2008 on as a lecturer at the post-master course ADMS (Architectural Design Management Systems) at the University of Technology in Eindhoven. In 2011 he started as a Professor on Innovation Building Process & Technology at the Avans Hogeschool, University of Applied Sciences (Built Environment & Infrastructure). In this position the focus is on developing the practitioners competence by connecting education, research and practice.

In architectural-research he studied the field of industrial-flexible-demountable architecture & construction for SBR, KIVI and SEV, the latter with a demonstration-project for Kropman – Utrecht Leidsche Rijn. Another field of research is related to different types of collaboration in the Dutch Building Industry. From 2000-2003 he did research on the culture-problems and collaboration between designers and engineers - Integraal Ontwerpen - commissioned to the Technical University Delft, the TVVL (Dutch Society for Building Services) and the BNA (Royal Institute of Dutch Architects). In 2004 he was honored with the B.J. Maxprize for these studies, publications and mission to practitioners and Professional Organizations. In 2005 he started part-time his PhD-research in the Architecture, Building and Planning department at Eindhoven University of Technology.